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A Program for the Committee on Watersheds

Committee Report

Earnest Boyce, Prof. of Municipal & San. Eng., College of Eng., Univ. of Michigan, Ann Arbor, Mich.; General Chairman, A.W.W.A. Committee 3—Watershed Protection and Maintenance

Presented on May 8, 1946, at the Annual Conference, St. Louis, Mo.

THE Committee on Watershed Protection and Maintenance, designated as Water Works Practice Committee No. 3, has been in process of organization for the past year. In establishing the committee, the Board of Directors provided for its functioning through three sub-committees, each dealing with a separate, but not necessarily isolated, aspect of the general subject.

Sub-committee 3A, under the chairmanship of Edward E. Minor, will study forestation as a means of improving the protection and reducing the maintenance costs of watershed areas.

Sub-committee 3B, under the chairmanship of John S. Longwell, will devote its attention to problems of watershed erosion control.

Sub-committee 3C, under the chairmanship of Lewis S. Finch, will analyze the factors that require examination in establishing policies for the public use of watershed areas.

The subject assigned to this committee is not new, nor is its engineering interest limited to problems in the field of public water supply. Consequently, the data already developed in the general study of soil conservation and erosion control should also be applicable to the watershed problems of public water supplies.

Purpose of Watershed Control

The water supply problems usually associated with watershed protection and maintenance practices relate more to the quality than to the quantity of water for public use. Although problems relating to the sanitary and physical quality of water will be first considered by this committee, this approach does not preclude subsequent

consideration of quantitative aspects, should such studies appear necessary. From the standpoint of water quality, catchment area controls and protection may be undertaken for two purposes: (a) to maintain the source of supply so that the water will require but minimal treatment; and (b) to prevent the quality of the untreated water from being impaired beyond the purification capacities of the modern plant.

When the former condition exists, the watershed controls serve as an integral part of an installation designed to protect the sanitary quality of the public supply, and, because of the dependence placed on these controls, they acquire major importance and significance. In the second case, however, the purification process in the water treatment plant is the important factor in the securing of potable water, and only nominal interest may be manifested in the quality of the untreated water, except when it becomes so grossly polluted that it approaches the safe load limit for the treatment plant. The ever-increasing pollution of certain major streams by sewage and industrial wastes has so added to the cost and difficulties of water purification that some cities may well consider the development of impounded storages on controllable catchment areas as supplemental sources of supply.

The practice of watershed control as an integral part of an installation designed to protect water quality has found its economic justification and greatest development in those areas where the physical quality—especially turbidity—of surface runoff meets potable water standards. As essential as sanitary controls are in protecting the biological quality of the water obtained from these watersheds, the physical quality of the runoff water reflects more the geological characteristics of the catchment areas than it does the effect of these controls.

Soils formed by the disintegration and outwash of granitic rock contain sand and other particles of sufficient size to protect the matrix of smaller soil particles against low-velocity water erosion. It is important to note that this geologic protection is not afforded in those soils formed by the disintegration of fine-grained marine sediments. Despite the flatter gradients of the streams that drain the plains areas thus formed, therefore, minimum turbidities of these runoff waters generally exceed permissible limits for potable use, and water filtration becomes necessary.

Watershed Control and Water Treatment

The development of water treatment methods suitable for the clarification of the turbid waters of the mid-continent regions progressed concurrently with an appreciation of the importance of these treatment methods for improving biological as well as physical properties. Later, water disinfection was introduced, first as a safety factor and then as a fully accepted treatment method, designed to provide an effective control of biological quality.

Gradually, as these treatment methods were generally accepted, they were extended to apply to all sources of water where turbidities indicated the need for filtration, regardless of the biological quality that may have been secured through recognized watershed protection practices. Because these methods of water treatment were found to provide an economical and at least an equally effective method of maintaining water quality, and because engineering attention continued to be

centered on the biological aspects of watershed controls, it is logical that interest in the protection afforded by watershed controls should have decreased.

It is possible that at least some of the uncertainty and confusion with regard to reasonable watershed control measures is due to the attempts to lift the standards applicable to one regional area and apply them to another without giving proper consideration to modifying factors. Outside the areas where watershed controls still serve as an integral part of the installation that insures water quality, protection and maintenance standards frequently represent community sentiment rather than authenticated engineering requirements. The committee may well have as one of its major objectives an evaluation of the factors that should receive consideration in the formulation of watershed use and maintenance policies, in order that they may reflect the type of protection needed under varying regional conditions.

Turbidity and Silting

One very important control factor relates more to the physical than to the biological quality of water obtained from the catchment area. Reference has previously been made to the high turbidities to be expected despite the relatively low stream flow velocities in areas of fine-grained soils. To this may be added the coarse-grained sediment loads carried by streams with steep gradients that traverse erodible areas. The deposition of this sediment and turbidity in the section of the valley developed for reservoir use results in a loss of storage capacity and a threat to the future usefulness of the installation that is just as serious as other, more frequently envisioned, pollutional loads.

Impounded storages provide an important source of public water supply, especially in the regions where soil is formed from clays and shales, with limited storage capacity for ground water. The silt load carried by the runoff from watersheds located in these soils may be of only nominal interest from the standpoint of the water treatment process, but it becomes of major importance when considered from the standpoint of protecting the storage capacity of the reservoir.

The costs of developing surface storage, as well as the limited number of sites topographically suitable for development as a source for any given water supply, emphasize the value of maintaining such watershed controls as minimize the reduction of storage capacity by silting.

An appreciation of the long-range importance of protecting the storage capacity of an impounding reservoir from the sediment deposits of an eroding catchment area may produce control measures and regulations as restrictive as any now enforced for the preservation of biological quality. A presentation and analysis of the data already available on rates of reservoir capacity loss due to sedimentation and a knowledge of control procedures should promote a more critical evaluation of the design factors applicable to this phase of the planning of water storage structures.

Soil Erosion Control

The sanitary survey of a watershed undertaken in one regional area for the preservation of the biological quality of the runoff water may well have for its counterpart a soil and land use

survey in areas where silt pollution is a hazard to storage capacities. Areas of easily eroded soil may require special attention to the preservation of soil cover. Watershed land use practices may require regulation in order to provide erosion control, either through public ownership of critical areas or through use restrictions on a contractual basis. There is a need for a more general comprehension of the soil erosion control obtainable through forestation and other productive land uses primarily selected to achieve this control.

The high productive value of fertile but easily eroded farm land adds an economic factor that requires careful consideration. The cost of catchment area control should be balanced against the long-range cost of the loss of water storage capacity by siltation or, in some instances, against the increasing costs of water treatment.

Unlike the private owner, the water utility is in a position of permanence and may plan the production of crops that are not grown and marketed on an annual basis. The present annual worth of future timber and lumber crop returns can be estimated even though their growth must be measured in decades rather than in years.

Silt control measures do not become practical despite their recognized usefulness until economic justification has been established. The committee may well have as another major objective a study of those factors that can make these control measures economically justifiable.

If the costs of effective watershed silt control measures are properly equated in the economic analysis of proposed reservoir sites, the cost of connecting pipelines and other appurtenant structures may have less relative importance in the selection of the site, thus making it possible to use more distant but cheaper and less erodible catchment areas. In order to avoid the sediment loads of flood flows passing through a reservoir storage, it may prove advantageous in some instances to develop headwater areas and to utilize larger percentages of the annual runoff.

Finally, it is suggested that the committee investigate the possibility of reducing silting rates through the study of special reservoir design features. Check dams and channel retards located above the elevation of the reservoir flow line have been used in the control of the heavier delta deposits, but these are less effective in the control of the slower-settling, finer particles that form the bottom sediments. Changes in spillway location and construction may serve to reduce the excellent sedimentation and decanting effect provided by conventional designs, although more must first be learned of the behavior of high turbidity density currents.

As the committee explores the field of its most effective usefulness to the members of the Association, it recognizes its dependence upon their cooperation in furnishing it with basic data that have been compiled from their years of experience. That cooperation will be needed.

Practical Forestry

By Edward E. Minor

Vice-Pres., New Haven Water Co., New Haven, Conn.; Chairman A.W.W.A. Sub-committee 3-A—Forestation

Presented on May 8, 1946, at the Annual Conference, St. Louis, Mo.

FOR the past fifty years there has been developing in this country a national forestry policy, accelerated, in the past two decades, not only by congressional action but by the interest shown by states, municipalities and private forest owners. It is, therefore, quite in line with modern trends that water works executives broaden their interest in forestry as it relates to the watershed areas from which surface water supplies are obtained. To protect and control the surroundings of reservoirs and streams, it has been desirable in many cases to purchase large areas of land. This at once presents a problem of land utilization which may directly affect the character of the supply, and also presents financial and aesthetic problems for those in charge.

History of Lumbering and Conservation

It might be well to have in mind, as a background for proposed forestry operations, a brief summary of the history of lumbering in this country, where for generations Americans have been living on their inheritance of virgin timber. The center of lumbering operations started in New England, moved to the Michigan pines in 1890, to the south in 1900 and to the far west in 1926. Large bodies of old-growth timber now remain only in parts of the western United States, and the idea that lumber of high quality was inexhaustible is now seen to be a myth. We are faced with a changed economy; second growth and conservation must supply the timber essential to the nation.

It is interesting to note, too, the gradual impact of these events on the federal government. In 1871 Congress stopped the railroad grants; in 1872 Arbor Day planting was instituted and the first national park—Yellowstone—was created; in 1875 the Division of Forestry was organized in the Dept. of Agriculture; in 1891 timber land reserves were set aside; in 1905 the forest reserves were transferred to the Dept. of Agriculture; in 1907 national forests were created; in 1911 the Weeks Law authorized acquisition of lands for national forests; and in 1925 the McNary Act on timber growth was passed. Thus interest in this subject has developed, and the answer to the problem of timber resource depletion is being sought in several ways. Public regulation of private lands may be utilized; or the lumber industry may become so enlightened that it will work to perpetuate its resources rather than to annihilate them.

Forestation on Watersheds

In line with this trend, A.W.W.A. Water Works Practice Committee No. 3A was appointed to study the subject of forestation.

In general, watershed areas are relatively small compared to national forests and parks. They usually have a diversity of cover, ranging from old, fairly open fields to stands of hardwood or conifers, and they vary in age and type, reflecting soil conditions. A field survey should be made to locate and to classify areas to be forested; a definite policy should be established for these lands.

The planting of open fields to form new forest cover is now recognized as good practice. Subsequent care, including control of disease, protection from fire and thinning, is also recognized as essential. The proper handling of natural stands, usually containing a mixture of species, is more complicated. For efficient results, both plantation and natural stands should be operated under a consistent policy and be directed toward objectives which can best be determined only by an experienced forester. Such a policy must be projected over long periods, often fifty years or more, and must determine whether the forest is to be a pure or mixed stand, of even or uneven age, and what type of tree should be dominant. It can readily be seen that an owner, whether he be an individual or a corporation, must have faith and idealism to carry through such a project. A municipality or a water board, owning land and having as its primary purpose the furnishing of a public water supply, is ideally constituted for such work. It benefits from an intelligent use of the land, not only by the financial returns that will come in time, but from the favorable effects on stream flow, the creation of an attractive setting for streams and reservoirs, and, with certain limitations, the provision of recreational areas for the enjoyment of the communities served.

The financial return of such a project is especially important because it is related at the start to the cost of acquiring the necessary land. The argument is plain; the cost must first be justified by the protection of the water supply; forestry is a secondary consideration. With proper handling, however, wooded areas may be made to yield an annual return which will in part justify their acquisition. The details of the returns from forest operations will not be discussed here; but the figures are available in publications of the Dept. of Agriculture, such as the "National Plan for American Forests," 1937. The experience of the author's own company with a tract of about 25,000 acres, under the general supervision of the Forestry School of Yale Univ., bears out these conclusions.

Evaluation of Returns From Forest Lands

By Ralph C. Hawley

Morris K. Jesup Prof. of Silviculture, Yale Univ.; Forester, New Haven Water Co., New Haven, Conn.

Presented on May 8, 1946, at the Annual Conference, St. Louis, Mo.

THE best method for estimating the returns from forest lands is to apply the average growth per acre per year over a long period of time. This is what is known as mean annual growth, or the average production per acre per year which may be expected during the lifetime of a forest crop. This figure, of course, varies greatly for different species of trees, sites and methods of treatment.

In the forests owned by the New Haven Water Co., for example, mixed hardwood stands composed principally of oak may be expected to produce an average of 200 fbm. per acre per year. Where hemlock is in mixture with hardwoods, the yield is increased over that of hardwoods alone. Hemlock produces 350 fbm. per acre per year. Plantations of white pine produce 600 fbm. per acre per year, and red pine 500 fbm. Norway spruce may equal the production of white pine.

Revenue Produced by Forests

The present average stumpage value of the timber is at least $7 per 1,000 fbm., based, not on war conditions, but on prices prior to the war. Thus, the mean annual gross production would be at least $1.40 per acre per year on hardwood lands, $2.45 on hemlock lands and $4.20 in white pine stands. On the basis of the present existing distribution of hardwood, hemlock and pine on the New Haven Water Co. property, the average gross returns should be at least $1.80 per acre per year for timber plus $0.50 per acre per year for small products. The total of $2.30 per acre per year may be increased by an increase in stumpage value and by converting more of the forest from hardwood to hemlock and pine.

These figures of growth are valid only if the forest is protected from fire and other injurious agencies and is allowed to grow along through the young stage until the trees become of suitable size for timber. That these figures are comparable to estimates made by other sources can be seen by referring to Table 1, taken from the *National Plan for American Forests* (1).

Forestation has not been practiced long enough in this country, however, to provide abundant data on gross and net returns, and estimates based on relatively few data must be used. From gross returns per acre per year must be substracted costs. An estimate of costs made on this basis, taken from the *National Plan for American Forests* (1, p. 1320), is given in Table 2.

The figures which apply best to the New Haven region are those given for "central hardwoods" and for "eastern white pine"—$0.41 and $1.13, respectively, per acre per year. Taxes are

TABLE 1

Estimated Gross Returns per 1,000 fbm. per Acre on Private Forests

Region	Growth Rate per Acre *fbm.*	Stumpage Realization Value	Saw-Timber Returns	Salvage and Culling Returns	Total Returns per Acre
From Intensive Forestry					
New England	307	$9.00	$2.76	$0.50	$3.26
Middle Atlantic	275	9.00	2.48	0.50	2.98
Lake	268	9.21	2.47	0.50	2.97
Central	217	9.00	1.95	0.50	2.45
South	365	9.36	3.42	0.50	3.92
Pacific Coast	559	5.55	3.10	0.50	3.60
North Rocky Mountain	348	9.29	3.23	0.25	3.48
South Rocky Mountain	126	9.29	1.17	0.13	1.30
From Extensive Forestry					
New England	166	$9.00	$1.49	—	$1.49
Middle Atlantic	185	9.00	1.67	—	1.67
Lake	179	9.21	1.65	—	1.65
Central	140	9.00	1.26	—	1.26
South	257	9.36	2.41	—	2.41
Pacific Coast	213	5.55	1.18	—	1.18
North Rocky Mountain	175	9.29	1.63	—	1.63
South Rocky Mountain	79	9.29	0.73	—	0.73

TABLE 2

Representative Costs for Intensive Private Forestry
Cents per Acre per Year *

Type of Cost	Taxes	Other Charges	Protection		Timber Management			Total
			Fire	Insects and Disease	Cutting	Stand Better-ment	Plant-ing	
Spruce-fir hardwood	25	2	2.5	0.2	4.5	13	2.5	49.7
Eastern white pine	60	2	5.0	10.0	15.0	17	4.0	113.0
Western white pine	40	2	12.0	11.0	12.0	1	3.0	81.0
Ponderosa pine (California)	40	2	8.5	2.0	10.0	1	2.0	65.5
Longleaf †	20	2	7.0	—	3.0	4	1.0	37.0
Central hardwoods	25	2	6.0	—	3.0	3	2.0	41.0
Douglas fir (Pacific coast)	50	2	8.0	—	3.0	1	1.0	65.0

* These are generalized costs for forest properties, in which at least half of the stand is assumed to be either virgin forest or merchantable timber. Silvicultural cutting charges, stand betterment and planting are charged off at 1 per cent per year, as a capital investment. The figures are based on present costs in national forests and other available data, but cannot be safely applied to any one individual operation, although they may represent fair averages for very large properties.

† Typical second-growth turpentine forest in the South.

the largest single item of cost and make up $0.25 and $0.60, respectively, of these annual costs. If now these costs are applied to the local hardwood forests, the net return per acre per year amounts to $0.99 ($1.40 − 0.41), and for white pine to $3.07 ($4.20 − $1.13).

Another estimate of gross returns and costs, for planting and growing white pine in southern Connecticut, is given in Yale Forestry School Bulletin 53 (*2*). The gross returns during the 60-year period required to produce a crop of white pine are estimated at $516 per acre, or an average of $8.60 per acre per year. Costs are estimated at a total of $118.37 per acre, or $1.97 per acre per year.

Expenses ordinarily incurred may be classed as taxes, carrying charges, stand betterment and planting. Fire, insects, disease and wind, although not direct expenses in themselves, often require expenditures for prevention and control, usually included under carrying charges or stand betterment. Just how greatly the average damage from injurious agencies reduces the net returns cannot be foretold. If forest lands are properly managed, however, salvage and control operations are undertaken, and the losses from injurious agencies are reduced to a relatively small proportion of the average annual income. When wisely directed, expenditures by water boards need never be so great as to make timber growing financially unprofitable.

In fact, water boards are likely to be in a better position to grow forest crops cheaply than many forest land owners, because much of the overhead involved in land ownership has to be borne anyway by water boards, which must own portions of the land on their watersheds. Thus all of the tax burden (until an increased tax is laid because of the accumulation of timber) and a good share of the carrying charges, which include such items as interest on investment and maintenance of a field organization, will have to be paid anyway, whether or not forest crops are grown.

As a concrete illustration of what may be expected, the forest lands owned by the New Haven Water Co., approximately 22,000 acres in extent, when once brought into productive condition, should furnish an average net return of $2 per acre per year. At the present time such a return is not being obtained, although portions of the property have been under forest management for over 35 years. Financial returns lower than the real productive capacity of the area forested are characteristic of most watershed forests.

Present Income Level

The reason why water companies today are not deriving net incomes commensurate with the potential growth possibilities of their forest land is that nearly all these lands are not yet in condition to produce their full growth rate. The growing stock of wood which covers the land is inadequate. If the trees are young and small in size they are suitable only for cordwood, and in the younger stages of development cannot even be sold for cordwood. If the trees are culls left after logging operations or are of species incapable of producing timber, like gray birch, they occupy the area to the exclusion of healthy individuals of good species.

Only as a growing stock of trees is developed, of size, kind and quality merchantable for timber, can the potential growth of the land in timber be realized. Although the mean annual growth of even the youngest stands is

figured at the rates listed earlier in this discussion, these growth rates must be allowed to operate for many years before the accumulated growth can be cut in the form of timber.

Very often this simple fact is not thoroughly appreciated. Timber is a crop which requires the use of the land for many years. When a forest property is in good condition, with an adequate growing stock, there will be trees of all sizes and ages in the forest, ranging from young seedlings right up to mature timber and then the full productive power of the area can be utilized and the mean annual growth of the whole tract harvested each year.

Very few water boards have forests with an adequate growing stock. Overcutting, usually by former owners of the properties, and lack of protection from fire are the principal reasons for the deficiencies in growing stock.

A secondary reason for unsatisfactory net incomes from watershed forests is the fact that forestry operations carried on by water boards frequently are not conducted with primary reference to the cost factor as it affects the success of the forestry operation. Operations in the forest to be financially profitable are best conducted on a piece-work basis rather than by day labor. To obtain efficient results when day labor is used, the laborers must be skilled in woods work and must be closely supervised by a foreman who himself knows how to carry on woods work inexpensively.

Many water boards, however, find it advantageous to use temporarily in forestry operations some of their permanent men skilled in the maintenance of water mains, when not needed for this regular work. Indeed, one of the advantages to a water board of carrying on forestation is that the forest furnishes a supply of useful work projects adequate enough to absorb all surplus labor which the organization temporarily does not need in their usual occupations. It stands to reason, however, that labor thus obtained temporarily for forestry operations will not have the skill in woods work or the interest in such work which is essential for keeping costs at a reasonably low level. It is to the advantage of a water board to use men in this way and the policy should be continued. But seeing the high costs of such work in the forest compared with the returns has led many water board managers to believe that forestry operations are unprofitable.

Another factor which adds to this impression is that frequently too much unnecessary clean-up work is done. The approach must be one of sound commercial sense rather than concern for appearances which so dominates many water supply operations on lands adjoining reservoirs. The two operations must be clearly separated, remembering, however, that commercial timber growing and watershed maintenance correct in its sanitation can be applied on the same tract. The average water board manager has difficulty in knowing when to turn from the aesthetic lawn-mowing, leaf-raking, brush-cutting, litter-burning, ornamental planting technic (some or all of it appropriate over limited areas close by reservoirs, streamways and pumping stations), to a woods operation which entirely eliminates manicuring of the landscape and accepts or discards each detail of operation on the basis of its cost in relation to the ultimate financial return.

So long as his appropriation lasts, the water board manager has a tendency to go too far into the woods with

his aesthetic and clean-up work. The intention here is not to criticize such activities but to point out that the conception that any of this work is a part of forestation is erroneous and has helped to lead water board managers to the belief that growing forest crops cannot return a profit. The two lines of work are each of use in watershed management. Let the management decide the areas upon which each of the two are to be used and carry on within a given area only the type of operations appropriate to it.

Effects of Forestation

Forestation as applied in watershed management should not be confined to tree planting but should include the management of all forested areas for the production of tree crops. What advantages water boards may expect from applying forestation on their watersheds may be explained briefly:

1. When the growing stock has been brought into condition, an annual net revenue can be secured from forested areas which is larger than that obtainable through any other use consistent with proper sanitation of the watershed.

2. An outlet is provided for use of labor permanently on the payroll, but temporarily without work.

3. Forests furnish effective protection to watersheds. Their influence on erosion and silting is known, but less appreciated is the fact that the forests most valuable in protecting watersheds are those in which systematic cuttings are made to reduce forest density, and heavy accumulations of big old timber, which itself uses too much of the precipitation.

Aspects of the protective influence of forests that should be considered include their effects on total runoff and on the division of this runoff between surface and underground flow. A well developed forest increases the permeability of the soil and consequently increases the rate of infiltration of water into the soil.

Forests also lessen the pollution of water, as increased infiltration should result in a greater filtering action to remove dirt and germs. This should be true whether the water finally seeps deep into the soil or drains off rather quickly after passing through the forest litter and upper soil layer.

Another important function forest cover performs is to lower the peaks of runoff, whether caused by rain or by melting snow. Trees break the force of precipitation and bring it to the ground more slowly than when it falls directly upon the ground surface. The mechanical action of the litter and the greater infiltration of water into forest soils result in lower maximum heights for some floods and maintains the flow of water through underground seepage during periods of low precipitation. Snow melts more slowly in the forest than in the open, and is thus fed more gradually into the streams. On the other hand, the forest, particularly dense conifer forest, intercepts a considerable percentage of the snowfall and never allows this to reach the ground, the snow evaporating from the crowns of the conifers. A mixed forest, made up of clumps of hardwoods and of conifers, usually permits a greater proportion of the total snowfall to reach the ground than does a solid conifer stand. The conifers have the effect, however, of furnishing shade and delaying the melting of the snow in these mixed stands for a longer period than occurs in hardwood stands, which have no leaves in the wintertime.

The effect of forest cover on the amount of precipitation is a myth, so far as man is able to control it. On the contrary, the distribution of forests is controlled by the precipitation, not the precipitation by the forest.

Forests do influence the temperature of the water, and water coming from forested watersheds may be expected to be colder than that coming from a bare watershed.

The protective value of forests on water compared with some other types of cover, such as grass or woody shrubs, is somewhat greater, although under certain circumstances either grass or shrubs may furnish as good protection as do forests and sometimes may even be better. Forests do use an appreciable part of the precipitation, either by the mechanical interception and subsequent evaporation of moisture from their stems and foliage or by consumption during the life processes of the trees themselves. Water is taken from the soil through the roots and evaporates from the crown of the tree, and the amount so lost is of course greater than would be lost from a type of vegetation with a smaller crown spread.

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Forest Influences on Reservoir Watersheds

By E. N. Munns

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Presented on May 8, 1946, at the Annual Conference, St. Louis, Mo.

THE relation between cover conditions and water resources is close and continuous; both simple and complex; often not understood and frequently misrepresented. It is not always the same. It varies with the season, topography, soil, climate and the type and character of the forest itself. It varies also with time.

Effects of Forests Upon Water Supply

A few facts and principles may be reviewed:

1. Forests probably do not affect precipitation greatly. Information, however, is not definite; there is some indication that the complete denudation of forests and the exposure of soil over a considerable area results in some precipitation changes that neither foresters nor meteorologists can satisfactorily explain. In any event, the effect of forests on the total quantity of available water supply is not an important factor.

2. Forests use water. Like animals, plants need water in their growth and in their ordinary functions of metabolism. Some trees get along with much less water than others, just as a cactus gets along with less water than a begonia. Some species of trees need 3 to 5 ft. of rainfall in a year, whereas others need as little as 6 in. Much more water is used during a short period of maximum growth than during a 6-month dormant period. One type of forest uses 6 in. or more of rainfall in a single month in early spring. Forests throw off water into the air in accordance with the same general laws that govern evaporation: more water loss takes place on dry windy days than on quiet humid ones and on bright days than on cloudy ones or at night.

3. Trees cause water losses through interception. The crowns of the trees —the branches and foliage—catch and hold appreciable quantities of water on their surfaces. Much of this is promptly evaporated into the air. When in full leaf, trees like the oaks cause several times the water loss that they do in early spring when their branches are bare. The percentage of rain water from a single storm that is evaporated into the air depends not only on the intensity and amount of rain, but also on the kind of trees, their size, the density of the stand and, of course, the season. Trees, especially conifers, catch and hold snow, and a surprising amount of water is thus kept from the ground. In some areas, this one factor may cause a considerable reduction in the total amount of water available for use. Interception losses may amount

to as much as 6 in. in a single year, and under some conditions may be more.

4. Forests reduce evaporation. A forest-covered soil evaporates much less water than a bare soil. In fact, there is some evidence that the water losses from a bare soil by evaporation may be as great as the amount the plant cover utilizes in its growth processes. We do know that, by reducing evaporation, forests conserve an appreciable amount of water.

5. Forests protect the soil from erosion. This is one of the most widely recognized benefits of the forest. The tree crowns reduce the force with which rain strikes the ground and the protective soil cover of litter and minor plants makes certain that the surface soil particles are not disturbed or shunted around by raindrop splash. Furthermore, the forest so holds the soil in place that even when surface runoff takes place in the woods, it causes but little soil displacement.

6. Forests build soil. The roots of many forest trees forage deeply in the soil for many essential chemical elements. When the leaves fall, these elements are largely returned to the soil to enrich its surface. As the leaves decay, humus develops and this humus aids the soil physically, and, as physical and chemical conditions improve, biological conditions also improve. In turn, as the soil is enriched, both its infiltration capacity and its water-holding capacity are greatly increased. Studies have repeatedly shown that the infiltration and storage rates of soil under a protective plant cover range from a few to many times greater than they are for the same soil when it is unprotected.

7. Forests protect the soil from frost. Forest litter develops acid solutions which have lower freezing points than pure water, and even if the water in the litter does freeze, the litter does not form a solid, impervious mat because the pores are large. Thus forest soil is still largely open and receptive when field and pasture soil are frozen so solidly that infiltration of water is precluded. Tests of infiltration using air temperatures below freezing, applied water at 33°F. and frozen soils disclosed that the rate of infiltration into the open soil was practically zero, whereas that of the forest soil remained high. In the spring, the forest soil is free of solid ice much before the open soil. Consequently, when deep snows melt, the water formed infiltrates into the forest soil but largely runs off from areas of open soil.

The forester thus has the power to control his water resources. By keeping the forest dense, he can reduce flood flows. By planting trees on idle and eroding land, he can virtually stop erosion and prevent harmful sedimentation. By cutting trees which are heavy water-users, he can make more water available. By removing those trees which cause a considerable evaporation of snow and rain through interception, water can be saved for use by man. By changing the composition of the forest, water can be conserved or lost. By maintaining the soil at maximum infiltration rates, groundwater supplies can be augmented. By burning the forest, runoff can be increased greatly.

The forester, therefore, can modify the rate at which water runs off a watershed, the volume available for runoff and the quality of the water. Conceivably he might save or lose 6 to 12 in. of rainfall a year. What he can or cannot do depends on many factors, some of which are only now coming to be recognized.

Water Supply Requirements

Over-All Aims

Some of the more important supply requirements which the water engineer must consider may be reviewed briefly. These requirements, from the water users' point of view, might include:

1. Ample yields. These, whether surface or underground, must be sufficient to meet not only present needs but reasonable demands for the future as well.

2. Desirable distribution of seasonal flows.

3. Usable water. By usable water is meant that which arrives at the intake or into storage facilities in a condition that will not cause physical damage to the water works, deplete storage facilities at excessive rates or result in high treatment costs.

4. High quality water. By high quality water is meant water relatively low in harmful bacteria or in undesirable matter, the treatment or removal of which does not require costly outlays.

5. Supplies available or accessible at reasonable cost.

The relative weight of any one of these requirements naturally differs with location, the source of the water, the size of the area involved and a variety of needs or situations. They undoubtedly can be expected to change in any one area over a period of time, and, as technological processes develop, some may become of minor importance.

Whether these requirements can be satisfied by any kind of treatment or management of a water source area is difficult to determine. Often the source of the water supply is the decisive factor. If the source is a large stream, there may be few if any specific things that the water engineer can do on the watershed to remedy conditions. But when the water manager has a considerable part of the water source area under his control, he can do a great deal to meet the requirements, much more than many might realize. And the more of the watershed the manager can bring under his control—directly or indirectly—the more adequately can these requirements be met.

Specific Action

If he has control or ownership of a major portion of the water source area, the manager must make many specific decisions. Within the limitations imposed by requirements of public health and the necessity to safeguard investments, the engineer has considerable latitude in his choice of action. From this standpoint, he might be interested in answering such questions as the following:

1. Will the quantity or quality of the water be improved by any special forestry practices that may be undertaken on this area?

2. Should municipal watershed forests be closed entirely to all use, or, if it is decided that they should be used, what form and intensity of use should be permitted? What factors should be considered?

3. From the standpoint of water supply, should conifers such as pine or spruce be favored over hardwoods and, if so, where and under what sort of conditions?

4. What kind of forest should be encouraged about the shores of lakes and reservoirs? What mixtures and densities should forestry practice aim to produce?

5. If conditions appear to permit the removal of forest products, what intensities of cutting practices should be

undertaken and what provisions for logging or transport should be developed to minimize the likelihood of damage to water values?

6. If tree planting is considered desirable or necessary, what trees should be used and how should planting be undertaken to develop most rapidly protection of the soil against erosion and improvement in soil conditions?

7. How should the slash from logging operations be handled in order best to meet water supply requirements?

8. What character of a forest cover should be favored—large trees with little undergrowth, or dense forests of relatively small trees?

9. Should wildlife be fully protected on watershed lands, particularly the larger animals such as deer or elk? What about beaver?

10. Should road and trail developments be permitted in water source areas and, if allowed, under what construction specifications from the standpoint of runoff and soil stability?

Such questions as these have confronted water managers many times. They undoubtedly will continue to arise. Quite often answers have been offered based on other than watershed needs. But where the engineers had a free hand, they made those decisions which they believed carried the least possible risks. Sometimes decisions have been based on the advice of associates or consultants. At other times, information has been furnished by foresters or other conservationists, some of whom may not always have too well understood the basic relations between forests, soils and water. There are indeed relatively few, no matter what their experience, who can readily recognize and evaluate the many factors in watershed management that must be taken into account if maximum benefits are to be obtained and risks avoided.

Primary Objectives for Soil

No one set of management objectives can apply to every type of forest watershed condition or to every type of water supply. Variations in rainfall, in snow melt, in topography, in steepness and length of slope, in drainage pattern, in depth of soil, in geologic structure and in character of the vegetal cover make every watershed an individual problem. Indeed, watershed management is one field where generalizations, particularly about specific methods and practices, are not safe. There are, however, certain cardinal principles which should be universally observed regardless of the particular characteristics of the watershed or even of the methods employed in producing domestic water. These may be termed primary objectives, and relate to the soil:

1. *Soil stability.* Without soil stability there can be no hope of maintaining any satisfactory degree of seasonal distribution, usability or quality of water flow. Satisfactory supplies from unstable soils are possible temporarily for a longer or shorter period and then only at a considerable ultimate cost. Sooner or later, the results of unstable soil conditions on a watershed become increasingly evident.

It may therefore be postulated as an inflexible rule that no operations, practices or developments on any municipal watershed can be permitted or condoned which in any way tend to cause either the physical removal of the soil (as by erosion) or a breakdown in its internal structure. The

maintenance of a porous soil structure is vital in soil stability.

It has already been pointed out that soil stability is dependent upon the amount and character of both the humus content and the kind and activity of organic life in the soil. Expressed simply, all this points to the necessity of maintaining some kind of effective plant and litter cover upon the entire water source area. It also means that any exposed soil surface—whether it be a road bank, an overgrazed area or a borrow pit—should be looked upon as a menace which may cause damage or require costly remedial measures, and which any farsighted and conscientious water manager should try to combat.

2. *Percolation capacity.* A high infiltration capacity of the soil is closely associated with stability and, indeed, is often an indication of it. It is most important that desirable rates of infiltration be maintained, primarily to eliminate or minimize destructive surface runoff from storms of high intensities or long duration, or from excessive snow melt. Infiltration capacity is related more closely to the structure of the soil, to its organic content and to the adequacy of the surface plant cover than it is to the topographic characteristics of the area, including length and steepness of slope.

3. *Water-holding capacity.* Maintenance of the soil's optimum water-holding capacity is essential to achieve a more desirable ratio between subsurface flow and annual runoff, as well as a more balanced seasonal distribution of subsurface flow, particularly during dry periods.

If these three vital or primary objectives are observed in water source areas, water users may be confident that they will suffer a minimum of losses in water value attributable to the use of these lands by man. The author believes that these objectives can best be realized under a forest cover.

Secondary Objectives

A second group of objectives must also be considered in arriving at answers to such questions as those raised above. As previously indicated, the specific services, values and effectiveness of forest cover in water production or in flood and sediment damage reduction vary significantly from region to region and even among the different portions of a small drainage basin. In some localities, communities may need protection from flood or debris flows above all else, even at the expense of maximum water yield. In others, maximum usable yield may be the distinct requirement; and, in still other situations, various combinations of the two. To some extent these problems may be met by storage reservoirs. But even then the long-time utility of these structures depends upon the minimum sediment rates. Men cannot afford to waste their precious and relatively scarce reservoir sites by permitting sedimentation, even though such wastage may be justified economically.

The manner and extent to which the upland plant cover is removed or modified is of vital concern to the water users. The kinds, extent and intensities of use permitted in a watershed must therefore be worked out carefully on the basis of the physical characteristics of each area. The method or methods used to obtain water must likewise be taken into account in whatever development is followed in a given source area.

Manner of Meeting Requirements

The methods of meeting water supply requirements may be grouped into four categories, based upon the manner by which water supplies are made available:

1. Surface supplies obtained by direct stream intake. These supplies are taken directly from a stream, as Washington, D.C., takes its supply from the Potomac. For this purpose, it is desirable to have supplies of good quality available at reasonable cost and requiring relatively inexpensive treatment; to prevent extreme high and low flow (particularly the latter during extensive periods of little or no precipitation which often occur during hot weather when drafts on supplies are heavy); and, if possible, to develop a gravity-flow system.

2. Storage reservoirs with less than six months' capacity. Small reservoirs are relatively common in the more humid portions of the country. In the North Carolina Piedmont, for example, 22 municipal water supply reservoirs have an average capacity of only four months' consumption. Small reservoir capacity in relation to annual use generally prevails in other sections of the East, as in the Appalachian mountains and New England. In all such situations, it is particularly important that siltation rates be kept to the minimum, that turbidity be minimized and that reservoir inflow rates during periods of heavy draft be maintained at a maximum. Often small reservoirs are located at higher elevations where possible to permit gravity flow and keep production costs low.

3. Large storage reservoirs. Storage reservoirs with several years' capacity are most common where great variations in annual water yield are to be expected. In such localities, although it is desirable to minimize siltation rates, and so also tend to maintain minimum turbidity rates, the necessity from a short-term standpoint may not be great. On the other hand, it is desirable to achieve the maximum inflow of usable water during recharge periods in order to impound ample supplies against periods of sustained drought. The San Diego, Calif., reservoir system has a capacity said to be sufficient for perhaps six years of normal consumption.

4. Subsurface supplies obtained from wells. Well supplies must be safeguarded from sources of contamination and salt intrusion, and their quality must be checked closely for hardness content and the effects of declining water tables. The supply must be adequate, also, for periods of heaviest use. Another consideration is the rate of depletion, rate of replenishment and the opportunities for increasing replenishment by artificial means, such as water-spreading.

It is now possible to return to the problem of the specific management practices to be applied to water source areas and to discuss how some or all the requirements of an adequate supply from forested areas may be met when dealing with these four major sources of supply. It should be pointed out, however, that pollution as such is not germane to this discussion, and will not be considered.

Stream Intakes

Supplies obtained by direct stream intake require the maximum protection of the soil against erosion because displaced soil material may do much damage. This protection is most essential

where soils erode easily, where silt discolors water readily or where the amount of bed load is appreciable.

Direct stream intake also requires the maximum possible regulation of flow by natural means to minimize extremes of flow. This might be accomplished by maintaining the highest possible infiltration rates to reduce storm or surface runoff and by building up the soil storage capacity to a maximum. By so doing, it is possible to increase and extend the base flow.

Shallow Soils

Where watershed soils are generally shallow and the area is not excessively large, it is desirable to build up both the soil and the soil's capacity for water storage. This can be done by increasing the organic content and the volume of pore space of the soil. For the area above the stream intake, a dense forest is indicated. Where natural conditions permit, a mixture of hardwood species should be encouraged. An older forest (at least 75 years of age) is probably better than a younger one. Such a stand would be even more effective if supported by dense undergrowth. The value of most types of underbrush is in their root development, which aids in firmly anchoring the soil and in stimulating biologic activity, thus helping to create a maximum of channels and pore space throughout the soil mass. Such a forest is a primary soil-builder.

Reforestation of open watershed lands of this character can be accomplished with conifers. It would later be desirable in such planted stands, however, as well as in naturally pure conifer stands, to change them by gradual and systematic cutting over a period of years into mixed stands of conifers and hardwoods. Such mixed stands provide a much better watershed cover than pure conifer stands. The watershed forest may be logged, but it should be done conservatively, avoiding large openings and using logging methods that will not disturb the soil unduly. Adequate fire control is a necessity.

These practices on shallow soils will also yield other benefits. One of these may be relatively clear high-water flows during periods of excessive rainfall or snow melt, when the volume of available water exceeds the water-holding capacity of the soil mantle. Another is the reduction or elimination of damaging flood flows during periods of intense rainfall.

Deep Soils

So far as deep soils are concerned, the main problem is one of increasing or at least maintaining a high rate of water intake into the ground. Any kind of good forest with a substantial litter cover will provide the best possible opportunity to increase infiltration, thereby preventing or greatly reducing surface runoff and erosion and their resultant damages. A mixed forest is best. Cutting and logging that do not result in extensive areas of exposed soil can be permitted.

On both shallow and deep soils, any cutting or logging close to the stream should be done carefully, in order not to disturb channel conditions. Grazing should not be permitted on shallow soils and can be permitted on deep soils only if the livestock are kept away from the stream bottoms. Deer and big game should be kept down to such a point that they cause no erosion. Beaver are objectionable, primarily because of organic pollution.

Small Reservoirs

The main problems with reservoirs of less than 6 months' capacity are to minimize siltation, reduce water losses over the spillway and raise dry-season inflow to compensate for heavy summer draft. High rates of siltation are likely to occur where there are low ratios of original storage capacity (in acre-feet) to watershed area (in square miles) and soils erosive on exposure. Some reservoirs, as in the Appalachian Mountain region, not only have a high ratio of capacity to watershed area but fortunately are also located in areas where soils are not too erosive. This is not true, however, of much of the Southeast, as in the Piedmont, where ratios are not only largely inadequate but soils are highly erosive. Furthermore, many watershed lands in this area are privately owned, which usually means agricultural use of the less steep slopes and forests subject to varying degrees of abuse through overgrazing, woods burning and heavy cutting. In addition, these areas often contain inadequately maintained roads and highways.

Appropriate watershed practices would provide for maintaining the best possible cover and permitting the minimum of watershed disturbance by agriculture, fire, grazing, wild life, roads and logging. In erosive soil areas (such as the Piedmont), and in rough mountain terrain where cover disturbances may lead to slides or debris movement (as in parts of the Appalachians and New England), serious consideration must be given to the question of whether the additional revenues obtainable from timber are worth risking the water values involved. In areas of steep topography and other conditions conducive to flash flows, it may be most desirable to aim for the maximum possible density of forest cover. This should be composed chiefly of hardwoods, to increase soil storage capacity, and means foregoing timber revenue possibilities until such time as logging methods can be developed for removing felled material without increasing surface runoff or causing turbidity even for relatively short periods. It must be recognized, however, that although flash runoff will be reduced by these measures, the heavy transpiration draft upon soil moisture during the summer season by the plant cover may interfere with the need for increased reservoir inflow at such times.

A way can now be suggested with some confidence to meet this need during the summer drought. This is to reduce transpiration where the draft is greatest, as along stream banks. Experimental evidence collected over several seasons on some experimental watersheds of the U.S. Forest Service strongly supports the contention that a material increase in water yields per acre can be attained by this method, provided, of course, that bank stability is not endangered by removing the vegetation. Evidence shows that cutting vegetation from the immediate vicinity of the watercourses in a small drainage area provides a 5 to 10 per cent increase in daily summer water flow. The effect of this cutting is immediate but not lasting, for, as time passes and new woody vegetation returns, the increase is diminished. After about five years, additional cuttings will be necessary.

It is not yet known how much of the watershed area should be cut to achieve this reduction in losses. In the experiment, everything was cut on either side of the small drainage ways to an elevation of 15 ft. above the stream bed

at that point. This amounted to about 20 per cent of the area. In less steep country, this undoubtedly would be too much.

Also, everything along the stream larger than a broomstick was cut to the ground. It is not known whether this may be considered an excess, or what the saving in daily summer flow might have been had cutting been confined only to the larger trees, or the shrubs, or those species of trees which are known to be heavy water users.

If this procedure be followed, very little if any of the cut material should be removed from the watershed, as the disturbances caused by logging may be too great. If there is a fire hazard, the tops should be cut so that as much as possible of the vegetation lies close to the ground. In this way, the added litter and humus also becomes available and aids soil protection and soil building.

The best procedure for watersheds on shallow and erosive soils in relatively steep country is not yet known, but what evidence there is indicates that the forest should be dense but should not contain many large trees. The diameter of the trees should not exceed 6 or 8 in. to obtain the best water yields. Again, all cut material should be allowed to rot on the ground to aid soil protection and soil building. A watershed should not be cut completely at any one time, but partially and gradually.

On deep porous soils, removal of cut material may be permitted, provided it is done with care. Instead of keeping the forest down to a small size, individual promising specimens can be permitted to attain a diameter of perhaps 24 in. before being cut. If water supplies are not adequate, however, timber values must be sacrificed for water.

It is not possible to be very specific in naming the species of trees to be favored or discouraged. Some of the heavier water consumers among the forest trees are known, and when studies are more complete, it should be possible to recommend which species to favor when dealing with such watershed problems.

Large Storage Reservoirs

The object of managing watersheds tributary to large reservoirs should be to achieve the maximum of surface runoff in the shortest possible time after precipitation, without at the same time causing soil instability. The ideal condition would be a watershed of relatively steep slopes and non-erosive shallow soils of relatively low infiltration capacity. This condition, however, seldom occurs in nature. The practical ideal, therefore, would be to maintain the minimum amount of cover consistent with soil protection and the obtaining of minimum water losses through interception, transpiration and direct evaporation from the soil.

The possibility of achieving this objective is much less in sub-humid areas, with rainfall of 20 to 30 in. or less, than in the higher precipitation zones. In the drier regions, evidence indicates that relatively little is gained by practices bringing about markedly reduced transpiration, as such reductions are usually offset by increased soil evaporation. In addition there is always the danger of starting damaging erosive processes. In regions where snow is a major element in the total water yield, much more can be achieved by reducing snow interception and evaporation. This can be accomplished in conifer stands by creating openings of limited size within timber of relatively uniform density, and by removing the

heavily branched or so-called "wolf trees."

In humid areas, it is believed that higher water yields can be obtained when the majority of trees are small. This is done by frequent and light cutting over the watershed. Whether or not the forest products can safely be removed for revenue purposes may depend on the possibilities of using non-damaging logging practices.

Some types of cover cause smaller water losses than others and some types produce deeper and better humus than others. Conifers, for example, not only intercept more snow than hardwoods, but also do not produce as deep or as satisfactory a humus. Conifer stands probably provide a more immediate and greater volume of water from the same amount of water in the snow than hardwood stands. Hardwoods in turn may not be nearly as satisfactory as a grass or perhaps even a shrub cover. Grass, for example, tends to dry up in the summer, thereby using a minimum of water. Whether grass is possible as a cover will depend upon climatic conditions, steepness of slope, exposure and soil types and depths. It will also depend upon use. Grass is worthless if it does not hold the soil. In deciding between timber and grass, the worst possible rainfall conditions or snow melt rates should be considered, rather than the average; otherwise, serious damage may result from the high intensities of a storm that comes once in 50 years, or from an unusually rapid rate of snow melt.

What specific methods of reducing water losses and acclerating safe surface runoff can be applied? The answer will need to take into account two important factors: the permeability of the soil on exposure and its susceptibility to erosion. Thus, relatively, the least cover could be maintained on a naturally permeable non-erosive soil and the maximum cover would need to be obtained on the least permeable, most erosive soil.

The more erosive the soil, the less use there should be of the water source area, and the more intensive the protection it should be given. Where soil, topography and climatic conditions permit commercial logging, the danger of damaging silt or debris movements into reservoirs or of serious contamination would of course be less for large reservoirs than for small ones. Cutting at any one time need not affect a large portion of the area, and debris problems would therefore be easier to handle. The logging season may affect debris movement and the inflow of polluted matter.

One precaution must be observed, however, regarding large-scale or drastic modifications of the cover, whether undertaken to increase the yield of water or of revenue from the sale of marketable materials. In certain critical areas, such as tension zones between forest and woodland or between brush and grass, the moisture availability may be so limited and so sensitive to disturbance, or the erosion potentialities so high, that any appreciable changes in cover density may give rise to a process of accelerated soil deterioration. There are also indications that a very heavy depletion of the cover may set in motion forces that will adversely affect soil moisture relations for an exceedingly long period.

Well Supplies

Water source areas which replenish ground water should be managed to reduce runoff; increase infiltration of

water into the soil; build up the soil storage capacity to the greatest possible extent; and, where snow is appreciable, provide for the maximum absorption of melt. The best possible litter and humus cover should be sought.

Where ground waters are to be replenished, runoff should be reduced to a minimum and infiltration aided by the development of good humus conditions. On steeply sloping lands, contour trenches or other depressions will aid detention storage as will the trees, ground cover and of course the litter as well. On more level lands, detention storage is primarily a function of litter and humus.

Where there is snow, the stands should be so developed as to permit maximum amounts of snow to reach the ground. This means mostly a hardwood forest. Conifer stands should have openings into which snow can drift and be protected from evaporation, and where snow melt can be delayed. A forest is better than grassland for all areas where snow is involved because water from melting snow usually percolates into the soil throughout the winter, whereas the more exposed soils are relatively impervious when frozen.

On areas used as spreading grounds, a type of vegetation which will provide a plant litter and humus cover should be encouraged, to permit maximum infiltration with the minimum of maintenance costs. In one area in Utah, a municipality diverts flood flows, often somewhat muddy, directly into a small patch of woods which is carefully fenced against grazing. This small patch, only a few acres in extent, has infiltrated all the flow put into it so far, whereas expensive contour ditches and ponds silted over and required costly treatment to maintain absorption.

Forests on the replenishing areas for underground basins can be utilized almost at will; however, soil compaction or runoff ought to be avoided. This means that cutting and grazing should be light, heavy game populations should be avoided, fires should be eliminated and the area in road surfaces should be kept to a minimum.

High Quality Water

Investigations made by the Forest Service plainly show how the forest can provide water of high quality.

At Asheville, N.C., where all of the watershed is in forest, water treatment costs a few years ago were about $8.50 per mil.gal., compared to $27 for reservoir water in the North Carolina Piedmont, where only 50 per cent of the watersheds are in forest. Furthermore, there is no siltation of consequence in Asheville's $1,000,000 Bee Tree Reservoir. Although much saleable timber is present in Asheville's watershed, great care will have to be exercised in carrying on any lumbering operations. The fact that no filtering is required of the 2,500 mil.gal. of water delivered annually represents a saving of some $50,000 a year attributable to the good forest cover conditions.

Another example of the relation between forests and water quality is offered by a large pulp and paper company which prided itself on the high quality of its water and its policy of providing good living conditions for its workers. However badly it treated its other forest lands, the area from which it drew its water was rather well protected. To provide its workers with

good homes, the company sold some of its land near the mill to its workers at low prices.

When discussing water problems, it was learned that the company was spending about $3,000 a month to eliminate the silt and color from its water. It did not take long to see that the sources of this contamination were the homesteads of its employees, who kept gardens, pigs and cattle and the improperly constructed roads the company itself had built in the area. By moving its employees out of the drainage area, removing the livestock, planting up the cleared ground, closing many roads and treating others, the company quickly reduced its expenditure for silt control by about 95 per cent, so that its annual cost was less than what it had previously spent for only a single month.

Research in Watershed Management

In presenting these suggestions for watershed management, the author knows well that some of them are not too well substantiated by uncontrovertible facts. This is unfortunate, but the studies of the Forest Service have been directed towards other problems. In developing its research in forest and water relations, the Forest Service has spent perhaps more time in the development of basic principles than in the development of specific practices.

An Experimental Forest

That practice has not been wholly overlooked, however, can be illustrated by what the service is doing at the Coweeta Experimental Forest in western North Carolina. This is an outdoor hydrologic laboratory, a forested area of approximately 5,000 acres on which there are about 30 small independent watersheds, each with a continuously flowing stream. The topography is mountainous; the precipitation, mostly rain, is in excess of 80 in. annually; the storms are frequent; the soils, deep and porous. Conditions are so ideal that a 5-acre unit produces a living spring.

At Coweeta the service has embarked on a series of treatments of individual watersheds which include changing forests to crop land and pasture and studies of the effects of fire, grazing, cutting, logging and roads. Each individual unit has its own water stage recorder to obtain data on runoff, its own intensity rain gages, its own ground-water wells and other specialized equpiment needed for the local studies. A new series of watershed treatments is being planned this year. The work is done by a staff on which men trained in forestry, plant physiology, sanitary engineering, geology and soils are participating.

Other studies have been undertaken in other parts of the country, but most of them do not apply as specifically to water supply problems as those just outlined at Coweeta. This has been in part because there has been greater concern with the watershed conditions of western national forests under Forest Service administration. Then too, the work of the service has been more concerned with other problems than those of domestic or industrial water.

It is becoming more and more evident, however, that the latter deserve a prominent place in forest research. When a single industrial plant uses as much treated water in a day as a city of 300,000 population, when our growing urban population must use reconditioned water, when air-conditioning

is becoming a necessity to healthful working conditions, it is obvious that domestic water supply problems are becoming really critical. And with municipalities and industries turning more and more to forest areas for their supplies, it behooves foresters to be able to give advice on the management of these critical areas.

In the development of its research, the Forest Service follows a general practice of making problem analyses. Before getting too far into any study, it obtains as much information as possible on the particular problem. It attempts to break it down into component parts and to ascertain what the most important phases are. It is then decided to which one or ones major attention should be directed. In this way, the chances of initiating costly work without having a clear concept of where it is going are minimized, and it is possible to put time and effort into the most urgent phases. By singling these out, a maximum of returns can be obtained in the shortest time.

New Studies

The Forest Service is this year expanding its watershed management research, not only at existing centers, but in new ones. For example, in the East it expects to initiate one study in the Mississippi Bluff lands and another in the Carolina Piedmont, with plans for another study getting under way in the Delaware and Susquehanna River basins. In the West, current watershed studies will be increased and some new work started.

A stage has now been reached in watershed research when a new and critical look at the national picture is essential. The last over-all study was made nearly 20 years ago, and, even though it has been revised every 5 years and briefly reconsidered annually, the program is an out-of-date and patchwork affair. In the new over-all problem analysis, the service will want to take a look at all the various problems to see how far present work is adequate or inadequate, how it can make the maximum contribution to public service, where the work is most needed and in what field or fields the emphasis for the next decade or two should be placed. It will have to decide how much effort should go into research on basic principles and how much on practical problems, whether flood control is more important than the supply of water for irrigation, how far forests can aid in power production and where municipal and industrial supply problems fit into the general scheme.

A thorough national problem analysis, in which regional and local needs must be considered, is a time-consuming affair. It has therefore been set up as a 3-year undertaking, because other current work and activities must be continued.

As a first step in this process, a national survey has already been initiated. The main emphasis is on federally owned forest lands; the next on state lands; then on municipal and other public lands; and, last, on private or industrial lands. The second stage is now being approached. In the phase pertaining to municipal and related forest lands, it is planned to determine which problems are related to the condition, needs or uses of the water source areas. It is understood that the American Water Works Association already has much of the kind of data needed, but it is quite probable that the Forest Service will desire to supplement this information as it en-

counters specific problems. It has not yet been determined how this should be done, and pressures of other work have as yet prevented the service from devoting much study to the situation.

In the development of past research, the service has not worked particularly closely with the water supply engineers and watershed managers. There are many reasons for this, some valid and some not so valid. This lack of contact may not have been particularly serious in the past. But in view of new developments, what the service has to offer concerning the management of forested water source areas makes clearly evident that the time has now arrived when the Forest Service and the Association should get together. The special help and advice of the Association and its Watershed Committee will be wanted in problems and the research program. By helping frame the over-all national research program, by advising from time to time on needed changes or revisions, by critically reviewing current investigations on the ground, Association members will not only aid in the solution of some of their own problems, but also will aid the public in its efforts to obtain the maximum efficiency from the national water resources.

Developments in the Control of Erosion

By John S. Longwell

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Presented on May 8, 1946, at the Annual Conference, St. Louis, Mo.

TO those water utilities which are dependent for their supplies on reservoir storage, the matter of erosion control is a most important subject. Investigations show that in many places erosion is causing the washing away of topsoil in the watersheds; the creation of gullies; the scouring, widening and deepening of natural waterways; the washing of fills and cuts on highways and railroads; and, finally, the deposition of the eroded soils in the storage reservoirs.

As a result, agricultural and grazing lands are being destroyed and, most important of all, a great deal of valuable storage space is being lost in reservoirs constructed at heavy expense to many companies, communities and public agencies. Unless adequate steps are taken to curtail this erosion, the available storage will be reduced to such an extent that existing reservoirs will have to be enlarged or new reservoirs built to replace the lost storage capacity. The Association is well justified in undertaking the study of watershed control and in getting this important investigation under way. It should prove of great value to a large percentage of the members.

Work of the Erosion Sub-committee

Thus far the work on erosion of Sub-committee 3B of the Committee on Watershed Control has consisted of the selection of committee members, a review of literature and the preparation of a bibliography on this subject. It is anticipated that in the coming year its activities will be substantially increased.

The work of the sub-committee will be somewhat simplified due to the extensive erosion studies, investigations and construction programs carried on by the U.S. Soil Conservation Service. This important agency has conducted many detailed investigations throughout the country, assembled a great deal of data showing the loss of reservoir storage due to silting, conducted an extensive research program to determine the best procedure in reducing erosion, carried on actual field construction activities to control erosion in watersheds of various types throughout the country and observed the effects of such programs.

It has been the author's good fortune to have worked out a co-operative agreement with the service covering investigations, design of erosion control facilities, study of range management and the furnishing of trees, plants and grasses for planting. This has involved about 86 square miles of watershed. The work was well under way when the war curtailed all such activities, and thus far it has not been possible to resume the program. It has been possible, however, to observe the results obtained from the work already done, such as tree planting,

setting out of shrubs and grasses, reduction of stream grades by installation of drop structures, bank protection on channels, soil-catching basins and related works.

Using as a yardstick the results of the work thus far accomplished, it is felt that the program should be continued as rapidly as possible. The rate of reservoir silting can be greatly reduced and, from a financial standpoint, the erosion control program should ultimately result in great savings in expenditures on new construction.

It is believed that similar conditions exist at many other locations throughout the country, and that information on erosion control, methods of correction and the results to be expected will be of value to water utilities in general.

Committee Aims

Accordingly, Sub-committee 3B is starting out on its program with three specific objectives:

1. Collection and summarization of available data on loss of storage due to silting of reservoirs.

2. Assembly of data on the best corrective measures.

3. Determination of the results that have been obtained where a well-designed program has been partially or completely carried out.

The committee expects to rely greatly on the Soil Conservation Service for use of the large amount of data accumulated by that agency. In addition, it would like to have any useful data that may be available from members of the Association and others interested in this program.

Erosion Control on Watershed Lands

By Carl B. Brown

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Presented on May 8, 1946, at the Annual Conference, St. Louis, Mo.

IN 1940, approximately 74,300,000 persons in the United States—a large part of the urban population—were being served with treated water. A little more than two-fifths of the water treated had to be filtered to remove the suspended sediment content, and nearly all of this water came from surface runoff. Thus, about 32,000,000 persons were served by filtered surface water. The water run through filtration plants in 1940 was approximately 1,400 billion gallons, or enough water to cover the entire District of Columbia 97 ft. deep. These statistics give some conception of the significance of sediment as a factor in water supply.

Condition of Watersheds

The physical condition of a watershed—the nature and extent of vegetal cover, the type of land use and the character and extent of soil erosion—has a tremendous effect on the quantity, quality and cost of treatment of surface water. For water works men, the three most important watershed problems are: (1) the silting of impounding reservoirs; (2) the cost of water filtration; and (3) the stability of stream flow, which is reflected in costs for flood protection, size of spillways and size of impounding reservoirs required to provide a constant and uniform water supply.

Dangers of Silting

In 1941, the author pointed out (1) that studies by the Soil Conservation Service indicated that 21 per cent of the nation's 2,600 impounding water supply reservoirs would have a useful life of less than 50 years as a result of silting, and another 25 per cent would last only 50 to 100 years. As the average age of our water supply reservoirs is now more than 20 years, this represents a critical condition, one that will involve large additional—and largely avoidable—costs to the taxpayers of many communities within the next few decades for enlargement and replacement of reservoirs. For this reason, it is obviously important that reservoir owners and operators maintain a frequent check on the silting condition of existing reservoirs and act to solve this problem before it becomes more critical. The Soil Conservation Service has developed relatively inexpensive methods for making rough determinations, as well as more refined methods for making periodic detailed surveys.

Even if a particular reservoir has lost only 10 to 20 per cent of its capacity, this loss may represent a critical hazard, especially if demands on the water supply have increased as they have in so many cities during these last few years. Columbus, Ohio, discovered this fact

last year when a prolonged drought, beginning in June 1944 and accompanied by sub-freezing temperatures in December 1944 and January 1945, practically dried up the Scioto River. The city's two reservoirs on this river had, when built, sufficient capacity to store a supply for about 173 days at the 1944 rate of consumption. But silting had reduced the capacity by 30 days' supply when the critical period arrived about the middle of January. The city had to impose severe water rationing, and some vital war industries had to suspend operations for a short period. The thaw came about the middle of February bringing flow of flood proportions. If the city's reservoirs had only been able to store the extra 30 days' supply the previous spring in the space lost to silting, the situation would not have become critical.

Cost of Filtration

Studies made by the Soil Conservation Service of water treatment plants in North Carolina indicated that a marked saving would result from reduction of the suspended sediment load of streams (1). It was estimated that an average reduction of 25 to 30 per cent in the suspended load would save $1.50 per mil.gal. in the cost of chemicals and would result in an eventual over-all savings of $7 per mil.gal. as a result of smaller capital outlay for settling basins, filter plant units, power, labor and other costs for backwashing the filters and for flushing or cleaning settling basins. In most watersheds, it is not only possible but practicable to reduce the load of fine suspended sediment by more than 25 or 30 per cent through soil conservation practices. In some agricultural watersheds, the load of fine sediment could be reduced 75 per cent or more while still maintaining profitable agriculture or the best land use. Every treatment plant operator should analyze his own plant records to determine what savings would result both in immediate operating costs and in future plant additions and replacements from reduction in the sediment content of the water being treated, particularly during periods of storm runoff.

Stability of Flow

The influence of forests on stabilization of stream flow his been shown by many investigations. Soil conservation practices on agricultural land also tend to stabilize the water supply, reducing the peak rates of runoff from many storms and increasing the low water flow of streams. It is not yet generally possible to evaluate in monetary terms the effects of watershed treatment on the quantity and seasonal distribution of water supply, but there is convincing evidence that the effects of watershed control are most favorable.

Protection of Watersheds

Having recognized the benefits from watershed control, just what can cities or water companies or industries do to obtain better watershed protection? There is almost universal agreement that the best possible watershed condition is a well-managed and well-protected permanent vegetal cover—forest in natural forest areas, brush or grass where climatic conditions do not favor trees. A few cities and industries are fortunately so situated that they can obtain their supply from watersheds which are largely in their native cover. Furthermore, the land in such watersheds is generally in public ownership or is privately held in large tracts. Here the problem has been or can be solved by entering into co-operative

agreements with the landowners and with federal, state and local forestry agencies for fire protection, maintenance and improvement. Over the country as a whole, however, the great majority of surface water supplies come from areas subdivided into small private land holdings utilized mainly for farming and ranching. Such areas, in private ownership, present the greatest problem in watershed control now facing water works operators.

Small Watersheds

In this situation two courses are open. The water works operators may undertake to acquire the entire watershed, get it under permanent cover and set up a management and protection program. Or they may enter into some contract by which the lands will be adequately improved, protected and managed while remaining in private hands. For relatively small watersheds, purchase and management is often the most practicable course. As the watersheds grow larger, however, the obstacles to this policy are obvious. Complete purchase becomes too costly. Furthermore, the dedication of very much good, arable land to permanent cover would not promote the national welfare. We have even now less good land than we need for crop production, and the shortage is becoming more acute.

Before considering the control of larger watersheds which are mainly in private ownership, it may be instructive to note two examples of the benefits of purchase and erosion control undertaken on the initiative of water works operators.

In 1925, the town of Newnan, Ga., developed a new water supply, which included the construction of a 125-mil. gal. impounding reservoir. This reservoir had a drainage area of 890 acres of rolling and badly eroding land. About one-third of the area was in scrubby woodland, the remainder in cultivation or idle because of gullying. More than half the topsoil on the watershed had been washed away. The city at once embarked on a purchase program, and has now acquired all but 50 acres at a cost of $32,000.

The state Division of Forestry was solicited to prepare a plan for watershed control. On its recommendations, a farm was planted to pine as soon as it was purchesed. More than 100,000 slash pine have been set out and natural reseeding has been rapid. Wire and brush dams were built in the gullies. Eight miles of fire breaks were cleared. The watershed is now 83 per cent in forest, only 10 per cent in open land, and 7 per cent in urban area in the fringes of the city. A full-time city employee maintains a fire and sanitary patrol of the watershed as well as the lake, and supervises tree planting. Watershed improvement and maintenance has cost from $2,500 to $5,000 per year.

The Soil Conservation Service made reconnaissance surveys of this reservoir in 1937, when the purchase and planting program was not half completed, and again in 1945. It was found that the annual storage loss had been reduced from an average of approximately 632,000 gal. prior to 1937 to an average of only 179,000 gal. since 1937—a reduction of 62 per cent. Furthermore, since 1942 the maximum turbidity of raw water has not exceeded 200 ppm. although values in excess of 1,000 ppm. ordinarily occur several times in a normal year in nearly all southeastern streams. The water works superintendent states that there has been a striking reduction in the flashiness of runoff from summer

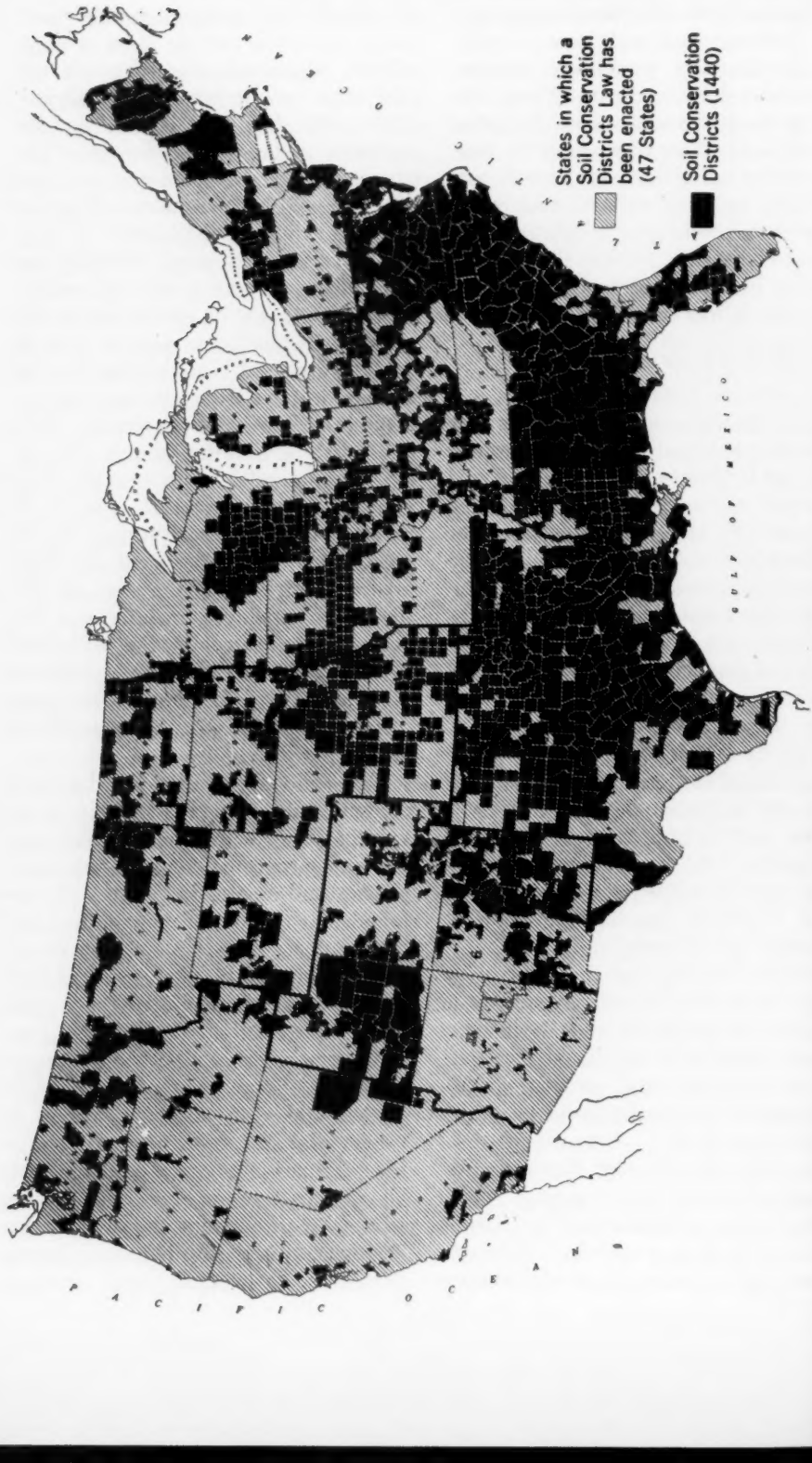
States in which a Soil Conservation Districts Law has been enacted (47 States)
Soil Conservation Districts (1440)
GULF OF MEXICO
PACIFIC OCEAN

FIG. 1. Soil Conservation Districts in the United States

storms and marked stabilization of outflow from the watershed.

Another outstanding example is the East Bay Municipal Utilities Dist. of Oakland, Calif., which has watershed areas totalling 86 square miles in the hills east of that city. It owns large blocks of land aggregating from 24 to 92 per cent of the respective areas of these watersheds. This district entered into a co-operative agreement with the Soil Conservation Service a number of years ago to determine the sources of erosion by appropriate surveys in the watersheds, and to develop a program of erosion control. The survey disclosed that the principal sources of sediment were: (1) channeling of natural water courses; (2) hillside gullies; (3) erosion on small tracts of cultivated land; and (4) land slips and slides, caused in considerable part by road construction and improper land use. The program recommended by the service, which is being carried out by the district, includes control structures in waterways and gullies, vegetative plantings to stabilize gullies, stream banks and road ditches and readjustments in land use.

Larger Watersheds

Consideration of the larger watersheds, where complete or extensive land purchase is not feasible, brings into the picture the Soil Conservation Districts. These districts are local units of government, organized and operating under state laws. They are set up and run by landowners and operators in order to protect farm and ranch lands from erosion, to conserve rainfall and to increase the productivity of the soil. The landowners in these districts elect their own governing body (usually 5 supervisors or directors). The districts have authority to ask and receive aid from state and federal governments; the Soil Conservation Service and other federal and state agencies furnish technical and educational assistance and sometimes a limited amount of planting stock, seed, equipment and other help. The districts have carefully formulated programs and specific work plans. The work of each farmer on his own farm fits into the district-wide plan. Often farmers work in groups, helping each other to apply good land use and conservation methods to their lands. Teamwork is the keynote.

Fig. 1. Soil Conservation Districts in the United States

Spread of Soil Conservation

As of February 15, 1946, there were 1,467 organized districts embracing 808 million acres of land (Fig. 1). During the period when attention was concentrated on the greatest war in history, the number of soil conservation districts organized by the farmers themselves almost tripled. This, in itself, is ample proof of the momentum of the soil conservation movement and its popular support. It appears likely that, within a very few years, virtually all privately owned agricultural and range land in the country will be within these districts.

During the war period, the rate of application of soil conservation practices has increased somewhat despite the loss of more than 2,000 technicians from the Soil Conservation Service to the armed forces. This has been possible because the farmers have learned more and more about conservation practices and have done more on their own with less technical guidance. During the past year, with conservation specialists returning in large numbers and with a favorable increase in appropriations granted by the Congress, the service has set itself an ambitious

goal—to double the acreage on which conservation practices and treatments are annually being applied. Through 1944, treatment had been completed on about 76 million acres; and, in that year, a little more than 10 million acres were treated. This does not take into account, however, the spread of many conservation practices to neighboring farms, on which it has not yet been possible to prepare complete conservation farm plans.

From these statistics, it might be inferred that the farmers are going to do all of the job of watershed control within a relatively few years; and, therefore, any concern of water works operators over this problem is needless. Actually, the opposite is true. The support of the membership of the Association is urgently needed now to provide adequate control in water supply areas, as a few more figures will demonstrate. There are a little more than 1 billion acres of farmland in the United States. All but 72½ million acres of this land is subject to erosion if it is not protected by soil conservation practices. In other words, more than 90 per cent of all the farm land in the United States needs some form of treatment or protection. After 10 years of national effort, slightly less than 10 per cent of all the land that needs treatment has been treated, and not all of this was treated in the best possible way. To complete the conservation job in the United States—to protect our precious heritage of soil and water resources—will take a vast effort, so vast that it might eventually cost almost as much as was spent on the war in a whole month last year.

Conservation Still Needed

The Soil Conservation Service has recently made a state-by-state survey to determine how much work remains to be done to control erosion. This survey further emphasizes the enormous job that lies ahead, despite the work already done. Just a few items will illustrate the scope of requirements: 125 million acres need to be changed from up-and-down hill farming to contour planting; crop rotation systems need to be developed on 213 million acres; strip cropping should be installed on 96 million acres; 111 million acres of range and pasture need to be seeded; 91 million acres need to be terraced; 12 million acres of gullied land need to be planted to trees; 1,200,000 stockwater developments are needed. It is estimated that the remaining conservation job will require 3,600,000 man-years of labor; 1,400,000 equipment-years for tractor and horse-drawn equipment; 2,500,000 tons of seed for establishing permanent cover and 27 billion seedlings and cuttings of trees, shrubs and plants.

Even at a much accelerated rate of application of conservation practices by the farmers, the complete job is going to take a good many years. The job will not be done in time to save many water supply reservoirs or to serve the present generation of water users adequately unless steps are taken by water works operators to accelerate the application of conservation practices on water supply drainage areas.

Financial Aspects

One more point is worth stressing. The compelling motive of farmer interest in soil and water conservation is to keep the good land good—to build up, protect and make more productive those acres on the farm that will yield the greatest return per dollar of cost. This is but another reflection of the

deeply-rooted profit motive in the American people and their enterprises. In former generations Americans found it more profitable to wear out a farm and move on westward to cheap, new fertile lands. There is no longer any good cheap land left in this country.

The expansion of our agricultural frontier now involves costly drainage, irrigation and flood control works. It is becoming increasingly profitable to conserve remaining good soils on older agricultural areas. This is the real underlying basis of the widespread acceptance of the conservation movement. But it has not yet become profitable, from a short-term point of view, for many individual farmers to install the more costly measures that are often necessary to reclaim lands already ruined or nearly ruined for agriculture by severe soil losses, deep gullying and rapid stream bank erosion.

To be sure, some farmers in good financial circumstances have enough pride in their land holdings to put all parts of the farm under good control, but the average American farmer finds it financially impossible to carry out all of the control measures and land use readjustments that a soil conservationist recognizes as essential for permanent protection of the soil. Although the farm plans which the conservationist prepares may show all of the work that is needed, the application by the farmer may represent only partial compliance with the plan. He is often simply unable to go any further.

After he understands their advantage, the farmer will generally accept contour farming, systems of crop rotation and cover crops. Usually he will go along on strip cropping, terracing, liming and fertilizing pastures, controlling to a reasonable degree the grazing use of the land, and adopting better methods of woodland management. The works which he finds more difficult to accomplish are the construction of adequate water disposal systems, soil-saving dams, the plantings necessary to control larger gullies and severely eroded slopes, and the control of bank erosion along the streams crossing his farm. The control of erosion along highways and particularly county roads is another problem on which not too much progress has yet been made. These badly eroded slopes, gullies, stream banks and roads are often the sources of the heaviest sediment production in the watershed and greatest damage to downstream water works.

Conservation Farm Plans

One of the most important aids rendered by the Soil Conservation Service to the farmer is the preparation of the conservation farm plan. This is based on a detailed conservation survey which shows the soils, slopes, degree of erosion and land use of the area. From the data obtained in these surveys, the land is divided into eight classes according to its capability. The need for land use readjustments and for various types of treatment and protection on watershed areas can readily be determined from these maps, implemented, if necessary, by special surveys of roads and streams.

Watershed Control Measures

Some practical steps can be taken to obtain adequate controls on watersheds which are largely in private ownership:

1. Water works operators can expedite the soil conservation program on their watersheds by employing one or more full-time soil conservationists

FIG. 2. Gully Resulting From Unprotected Terrace Outlets

FIG. 3. Same Gully Sloped and Sodded With Bermuda Grass

to work in co-operation with the soil conservation district or districts in farm planning, and give guidance in the application of practices and installation of structures and in maintenance work on the particular watershed. This is the course that the City of Decatur, Ill., has taken. For the past five years the city has appropriated $12,000 annually to employ two soil conservationists to further the work of the several districts in its large Sangamon River watershed.

2. Water works operators can undertake a land purchase and treatment program, based on recommendations of the soil conservation district and guided by the land capability maps of the area. Land purchased for watersheds should not be just a strip around the lake. Purchase should be based on the principle of acquiring the land where adequate treatment by individual owners cannot be obtained because of land condition, legal complications or other reasons, and where the erosion hazard is especially severe with respect to contribution of sediment to streams.

3. Funds can be made available under contract with the districts to be expended on particular types of treatments which are financially difficult or impossible for the average farmer to carry out. This was done by the city of Roxboro, N.C., which appropriated $1,000 to be used by the district in developing grassed waterways. Funds are needed in most districts particularly for those measures which are relatively the most difficult for the individual farmer to carry out, but which are often the most effective in controlling sediment production that affects water supply.

Examples of such measures are:

a. Grassed waterways, supported where necessary by terrace outlet structures and drop structures in the waterway;

b. Gully control work, including planting, sloping, minor structures, and diversions to prevent drainage into the gully. Figure 2 shows a huge gully at Yoakum, Tex., which resulted from unprotected terrace outlets. The same gully, after the terraces were rearranged to divert the excess water into vegetated diversion channels, is shown in Fig. 3. The gully has been sloped and an excellent cover of Bermuda grass obtained by solid sprig sodding, which also affords some grazing.

c. Stream bank erosion control. A severe instance of such erosion along the Wynooche River in Washington is shown in Fig. 4. Between 1935 and 1939, when this photograph was taken, six acres of land was lost in the area, resulting in enormous sediment production. The sloping, rip-rapping and brush matting work illustrated in Fig. 5 was done by a CCC camp the following summer. The farmstead in the background is protected by rock.

d. Soil-saving dams, channel control dams, drop inlet structures above road fills. Figure 6 shows a road culvert in Marion County, Mo., constructed with a riser to control a gully in the field above and to induce sediment deposition. The expense to the farmer, including 23 sacks of cement, was $20; all other materials and 35 man-days of labor were furnished by a CCC camp.

e. Sediment detention basins, which can often be combined with stock ponds that are useful to the farmer.

f. Roadside erosion control. In this the water works operators can also help by direct appeal to state and county road authorities.

g. Planting of abandoned, gullied land.

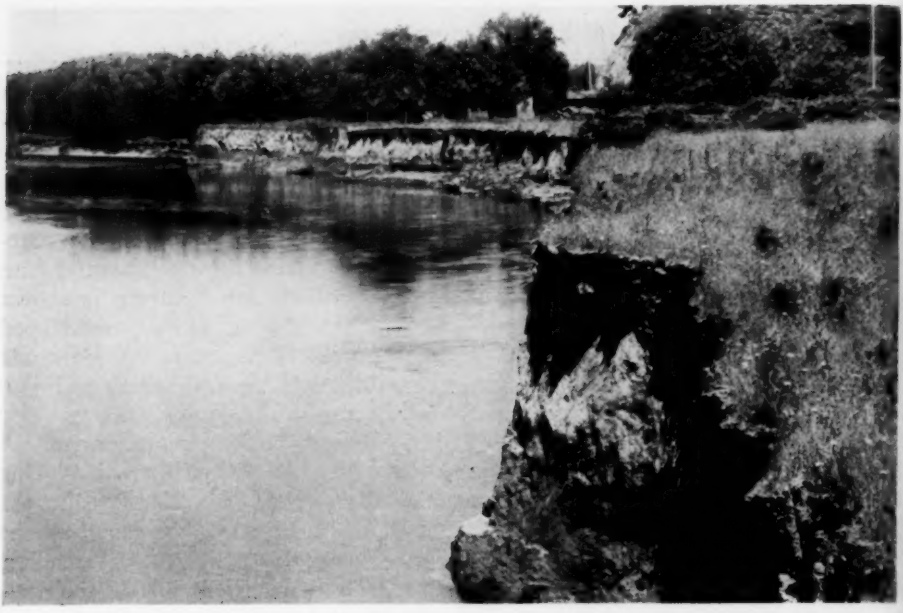

FIG. 4. Severe Stream Bank Erosion

FIG. 5. Same Bank After Sloping, Rip-Rapping and Brush-Matting Treatment

FIG. 6. Gully Control by Construction of Concrete Riser on Culvert

4. Excess labor can be used. Many cities and water companies employ permanent labor forces which in ordinary times have slack periods, even if only a day or two at a time. With continuing work projects in the watershed, such as tree planting or construction of small dams and culverts, these labor forces can be used on the days when they are not needed in town or at the water treatment plant.

5. Idle equipment can be put to work. The districts can nearly always use bulldozers, power shovels, ditch diggers or trucks on conservation work in the watershed on days that they might otherwise be idle.

6. Contributions of scrap materials will give material aid. Supplying second-hand pipe, fencing and many other scrap materials to the districts will pay a much higher return in erosion control than in the scrap dealer's yard. Supplying cement through the district may be all the incentive the farmer in the watershed needs to build a masonry check dam. Or some wire may permit him to place a willow matting for stream bank protection.

There is no need to emphasize that water works interests are already being greatly benefitted by the Soil Conservation Districts movement and that whole-hearted co-operation with the districts can result in rapid improvement and adequate control on privately owned watershed areas. The Soil Conservation Service stands ready to advise and assist in developing this co-operation.

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Public Use of Reservoir Lands and Waters

By Lewis S. Finch

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THE proper extent of public use of reservoir lands and waters can be determined only after careful study of the individual reservoir in the light of the public relations, the social, the economic and the health and sanitation factors involved. This is a problem of management as well as of sanitation.

Consideration must be given first to eliminating all uses which are not compatible with the economical production of a safe and satisfactory water supply. Purely social values must be subordinated to those of importance in the successful operation of the utility. Public relations aspects of the problem must not be overlooked, but they must be relegated to a position of secondary importance if the sanitary integrity of the water supply is involved.

It seems evident, in view of the necessity for giving consideration to such diverse factors, that rules of universal application cannot be established, but, rather, that general principles should be developed which can be used in studying individual problems of public use.

Such problems are by no means new. The Index to the JOURNAL shows that the subject of watershed protection has been under discussion on the programs of the Association since 1888. In that year, J. N. Tubbs presented the first paper on this subject (1). Several other papers (2–5) dealing generally with the protection of watersheds were published in the JOURNAL during the ensuing years, and, in 1923, a committee appointed by the Association to study watershed sanitation presented a comprehensive progress report (6). This report later was used as a basis for the chapter on "Watershed Protection" included in the *Water Works Practice Manual* (7) published by the A.W.W.A. in 1925. In this chapter of the *Manual,* the problem of watershed sanitation was discussed from many different angles, the trend of thought advanced by the report being exemplified by the following quotation:

> Efforts should be directed toward the restriction by statute of all activities tending markedly to pollute unfiltered water supplies, and those tending to pollute filtered water supplies to such an extent as to overload or to threaten seriously to overload ordinary purification processes.

Conflict of Opinion

This philosophy was well received in many parts of the country, but E. Sherman Chase, Cons. Eng. of Boston, Mass., took issue, objecting that the tenor of the report tended to "minimize somewhat the value of watershed sanitation, particularly where purification methods are employed" (8). He further declared that "purification methods are subject to the limitations of

human frailties; and, if interruption of purification methods occur, the chance of unfortunate results as regards outbreaks of disease are much less with a reasonably well protected watershed than with one wholly unprotected."

That this viewpoint was not necessarily that of water works men throughout the country is best brought out by a paper presented at the San Francisco Convention in 1928 by Helman Rosenthal (9), Director of Laboratories at Dallas, Tex., in which he declared:

> This subject is necessarily controversial. Some would fence off all reservoirs and let no one have a look at them. Others would throw them wide open. Neither of these opinions are based, of course, on scientific facts.

He also said that, in his opinion, the only criterion for deciding

> . . . whether hunting, boating, and fishing or even bathing should be permitted is the load that the water purification plant can safely and economically handle. . . . It may be argued that it would be ideal to eliminate all possible pollution from our raw waters. Such a condition, even if desirable, would be uneconomical. In this connection, it must also be remembered that there are vast areas in the United States that have no large bodies of water, and to deny the citizens the use of such water as is available would be to deprive them of something very essential to their well-being.

Perhaps it has been unfair to quote these writers after a lapse of about eighteen years, for one's viewpoint often changes with the passage of time. Nevertheless, whatever the authors' present opinions, there are others today, and many of them, who wholeheartedly subscribe to each of these divergent viewpoints.

It is not the purpose of this discussion to attempt to settle the controversy, for it is recognized that the existing differences in opinion are so great and, in many instances, so involved with traditional prejudices, that to secure complete agreement verges upon the impossible. Rather, it is hoped to arrive at a general scheme of analysis which, although it may not serve to reconcile the divergent viewpoints, at least may serve to stimulate discussion.

Any discussion of the limitations which should be placed upon public use of reservoir land and waters will be helpful to Sub-committee 3C—Public Use of Watershed Areas of the A.W.W.A. Committee on Watershed Protection and Maintenance. The sub-committee plans to consider the effect of various possible degrees of public usage of reservoir land and waters upon the operation of the water works and the well-being of the community served. From this study, it hopes later to be able to draw conclusions which will aid those developing an administrative policy for a specific reservoir.

The opinions advanced in this paper are those of the author, however, and do not represent, in any way, the viewpoint of the committee. These opinions, further, are being expressed largely in an effort to stimulate discussion, rather than to present an answer to the problem.

For the purposes of discussion, "public use" may be interpreted to include the development of resorts, boating, bathing, fishing, camping, picnicking, hiking, nature study and similar recreational and educational activities. In determining which, if any, of these activities may be permissible in the area of a given reservoir, the factors which should be considered are: (1) the effect upon the operation of the water works and the quality of the water

produced, (2) the social benefits for the community, (3) the effect upon public relations, and (4) the cost to the utility as compared with allowable expenditures for bettering public relations.

It may be noted that the factors suggested include matters of interest to management as well as those involving sanitary considerations. In that respect, this approach to the problem differs from those previously reported.

Quality of the Water

Of course, no public or other use of reservoir lands and waters should be permitted which tends to affect adversely the operation of the water works, either by endangering the quality of the water, by creating operating problems or by unduly increasing operation and maintenance costs. Capital expenditures not commensurate with benefits accruing to the utility in improved public relations should not be incurred.

Of primary importance, however, is the effect of the proposed public use upon the quality of the water supply served to the public. There is less divergence of opinion on the public use of reservoir lands and waters for unfiltered than for filtered supplies. Where filtration is not practiced, very limited public use, if any, should be permitted.

H. E. Moses, now Chief Engr. of the Pennsylvania Dept. of Health, in discussing the Rosenthal paper (9), made the following statement regarding unfiltered supplies:

Two general principles may be applied to a watershed to ascertain if some measuring stick can be adopted which will have more or less general application throughout the country, and in this connection it might be well to consider the "recreational use" of a watershed as comprising bathing, fishing, hunting and camping:

First, where the reservoir does not have a nominal long-time storage and where ways and means have not been installed or are not being operated to safeguard the sanitary quality of the water delivered to the consumers and where the catchment area is relatively uninhabited and untraversed by much-traveled highways, the recreational use of the catchment area does constitute a menace to the public health.

Second, where the nominal retention of the water in the reservoir can be construed as adequate long-time storage and where ways and means have been installed and are being operated to safeguard the sanitary quality of the water delivered to the consumers and the catchment area is inhabited or traversed by extensively used highways, the recreational use of such a catchment area does not constitute a menace to the public health. Persons so using these areas do not add an undue burden upon the self-purification to be obtained from the assured long-time storage and from the artificial ways and means which have been installed and are being operated to safeguard the sanitary quality of the water delivered to the consumers and hence, in such cases, consideration might be given to permit the public a restricted use of the watershed area, exclusive of the reservoir and the margins thereof.

With filtered supplies, the situation is far less critical, and more liberal use of reservoir lands and waters may well be permitted if other bodies of water are not readily available to the public. Mr. Moses also contended that:

There are certain streams used as sources of public water supplies, principally the rivers and major tributaries draining developed areas, having a relatively large volume of flow, used with a maximum of purification measures and where filtration of the water is the al-

most universal practice, wherein recreational use might be permitted with reasonable safety.

In general, fishing and possibly boating would seem to add little hazard where complete water purification facilities are available and carefully operated. Picnicking and other recreational activities, with the possible exception of swimming, would appear permissible. Mass bathing could be considered to constitute a hazard even with filtered supplies, although it must be admitted that examples can be cited where bathing is permitted with no apparent ill effect. Except under the most unusual circumstances, however, psychological considerations, at least, would make it unwise to permit swimming in reservoirs.

The maintenance of resorts or cottages upon reservoir lands seems quite undesirable even with filtered supplies. Again, it must be admitted that there are instances where such establishments are permitted without apparent untoward results; but, even so, it appears that such practices should be allowed only under the most unusual circumstances and under strict control.

Many sanitary authorities and public health officials accept the fact that public use of reservoir lands and waters does not constitute a sanitary defect in the water supply unless the type and extent of the use are sufficient to pollute the raw water grossly. In fact, the "Manual of Recommended Water Sanitation Practice Accompanying United States Public Health Service Drinking Water Standards, 1942" (10) contains no mention of recreational hazards in the discussion of filtered supplies, although it does list "insufficient restrictions on recreational use of streams and reservoirs, together with their marginal lands, in the local catchment area" as a possible sanitary defect of unfiltered supplies.

It seems unnecessary to discuss this angle of the problem further except again to point out that there are so many different circumstances to be considered that it is impossible to lay down rules which may be applied invariably.

Community Benefits

It appears unwise to permit public use of reservoir lands and waters unless a definite community benefit may result. Should other satisfactory recreational areas and facilities be readily available to the public, there seems no point in competing with the other facilities. Under such circumstances, it is believed that few, if any, recreational privileges should be extended to the public upon the reservoir lands or waters.

On the other hand, in regions where no other bodies of water are available, the water works quite properly can provide recreational facilities upon the reservoir property which are consistent with economic and health considerations. Where it is not expedient to permit recreational use of reservoir lands, it may be found desirable to set aside the restricted area as a bird sanctuary and game refuge.

It must always be remembered, however, that the prime function of the water works is to supply water and not to extend community service, no matter how desirable from the civic viewpoint.

Public Relations

Effectively controlled public use of reservoir lands and waters quite properly may be used as a means of im-

proving the relations of the water works with the public, provided that only such use is permitted as will not adversely affect the operation of the utility or the quality of the water. Particularly in regions where no other bodies of water are available to the public, the utility can make many friends by allowing the reservoir and its lands to be used by the public.

Money for promoting public relations quite properly can be included in the budgets of water utilities, and no better way of spending it can be found than in providing proper recreational and educational facilities for public use.

Cost of Public Relations

Economic considerations help to determine the justification of the public use of reservoir lands and waters. Whatever cost is incurred must generally be charged against the budget for maintaining or improving the relations of the utility with the public. Should the cost of extending recreational facilities exceed the amount properly chargeable to maintaining good public relations, the additional cost should be met by some other agency. Where costs so overrun, the discrepancy might possibly be met by establishing a concession and making the recreational facilities pay their own way. In any event, it is not only poor accounting to charge too much to good-will budgets, but it is also unfair to the water customers to make them pay for the recreational facilities of the community.

Summary

So many diverse factors determine the degree to which the public properly may be allowed to use reservoir lands and waters that rules of universal application cannot be established. Rather, general principles should be developed which can be used in studying the individual reservoir public use problem.

In any event, consideration may well be given to permitting such use of water supply reservoir lands and waters as may appear justified when compared with each of the following criteria:

1. The public use must be consistent with the economical production of a safe and satisfactory water supply. Where water supplies are unfiltered, public use generally should be restricted, if not completely prohibited. Where supplies are filtered, a much more liberal policy may be followed, and often many desirable recreational and educational uses permitted.

2. All public use of reservoir lands and waters which is permitted should be such as to result in a definite community benefit.

3. If consistent with other limiting factors, public use of reservoir lands and waters quite properly may be permitted as a means of improving the relations of the water utility with the public.

4. The cost to the utility of extending and controlling worthwhile public use of reservoir lands and waters must be commensurate with the benefits accruing to the utility. The prime function of the water works is to supply water and not to extend community service.

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An Improvised Curb Box

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A Contribution to the Journal

NECESSITY is the Mother of Invention" is an old saying particularly adaptable to the present day if we may consider "invention" to include "ingenuity."

All over the country, men in the water works field find themselves in open competition for the reduced supplies of materials that were once considered commonplace. Particularly is this true in housing construction, as well as in mercantile and small business demands.

The water works man has always taken pride in his product and its contribution to public welfare through dependable, continuous service. Now he is called upon to perform miracles of ingenuity to enable his plant to continue to operate, to produce, to deliver and to be maintained even at a precarious level. Crises in all these functions have occurred, and the story of each is an interesting example to all.

Necessity

The story of how ingenuity overcame a shortage in curb boxes—a very critical item—at the Akron, Ohio, Water Works is such an example. Some months ago, when it was becoming increasingly apparent that housing development and the demand for services would outdistance curb box deliveries, the Water Service Div. was called upon to devise ways and means to solve this problem.

With over 9,000 services installed in streets in advance of paving, but not in use, it seemed possible that in a crisis these unused boxes could be salvaged and reused. The scarcity of additional labor and the need for all existing labor on new installations at least postponed this procedure.

Invention

Finally, out of desperation was born a curb box made almost entirely of scrap materials gathered in junk yards and half-forgotten supply dumps. The idea may not be entirely original but a glance at the sketch (Fig. 1) will show that it is practical. The cost is much less than for new curb boxes, and it is believed that they will last just as long. If they should require replacement after many years, at least the added cost bridged a present emergency.

This short story is told in the hope that it will help others in a like dilemma, and that it may inspire others to the exercise of ingenuity in solving similar problems.

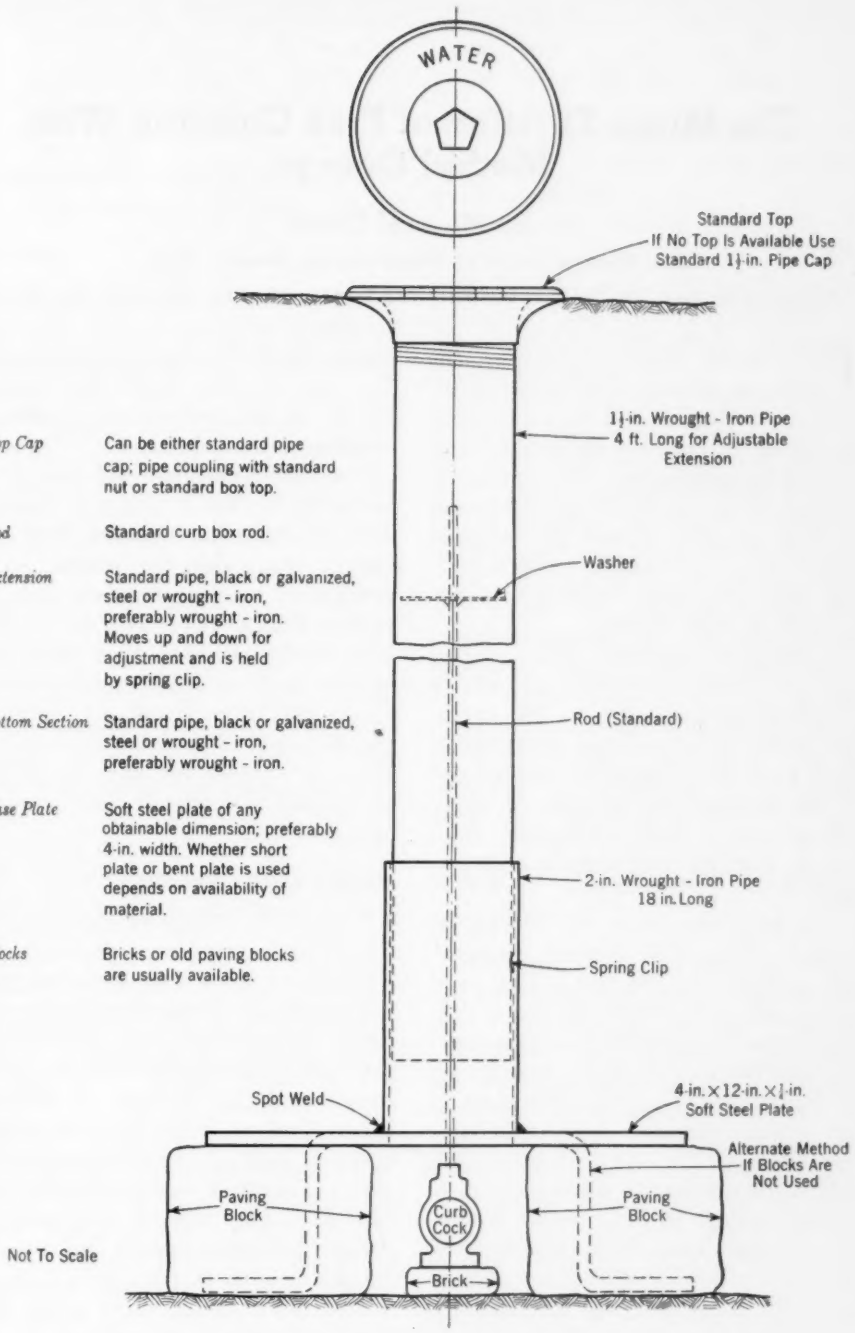
WATER
Standard Top
If No Top Is Available Use
Standard 1¼-in. Pipe Cap
1¼-in. Wrought - Iron Pipe
4 ft. Long for Adjustable
Extension
Washer
Rod (Standard)
2-in. Wrought - Iron Pipe
18 in. Long
Spring Clip
4-in. × 12-in. × ¼-in.
Soft Steel Plate
Spot Weld
Alternate Method
If Blocks Are
Not Used
Paving
Block
Curb
Cock
Paving
Block
Brick
Not To Scale
Top Cap
Can be either standard pipe cap; pipe coupling with standard nut or standard box top.
Rod
Standard curb box rod.
Extension
Standard pipe, black or galvanized, steel or wrought - iron, preferably wrought - iron. Moves up and down for adjustment and is held by spring clip.
Bottom Section
Standard pipe, black or galvanized, steel or wrought - iron, preferably wrought - iron.
Base Plate
Soft steel plate of any obtainable dimension; preferably 4-in. width. Whether short plate or bent plate is used depends on availability of material.
Blocks
Bricks or old paving blocks are usually available.

FIG. 1. An Improvised Curb Box

The Micro-Titration of Free Chlorine With Methyl Orange

By Michael Taras

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Presented on Sept. 20, 1946, at the Michigan Section Meeting, Traverse City, Mich.

THE recent trend in water works practice toward differentiation between free chlorine and chloramine has developed the need for estimating these kindred halogen forms. The titrimetric method of choice in the determination of total chlorine is the starch-iodide method (1). Distinction between chlorine and chloramine, however, is impossible by this method.

A demand manifestly exists, therefore, for a volumetric method capable of measuring one form to the exclusion of its closely related counterpart. Such a method is possible, making use of the spontaneous reaction of dilute methyl orange with elementary chlorine in a dilute hydrochloric acid medium.

The bleaching action of chlorine on methyl orange has received considerable attention in Europe. The most significant contribution to the understanding of the reaction and its numerous possibilities is a Dutch monograph by Holwerda (2). The first part of the monograph has been translated into English (3). According to Holwerda, the qualitative decolorization of methyl orange by chlorine in hydrochloric acid was first reported by Winkler in 1915. The test was subsequently converted into an empirical volumetric procedure and resulted in the uncovering of valuable data on the properties of chlorine and chloramines. By contrast, the American literature (4, 5) on the methyl orange-chlorine reaction is limited.

The methyl orange reaction is remarkable in that it offers a means of differentiating free chlorine from chloramine (6). For this reason, an investigation was undertaken into the various factors governing the reaction. This study revealed that an instantaneous and virtually quantitative reaction can be produced by regulating the amount of hydrochloric acid in solution. Under the same conditions, chloramine is practicaly inert to methyl orange.

Nature of the Reaction

The decolorization of methyl orange by elementary chlorine proceeds on a molecular scale in a dilute hydrochloric acid medium. Preliminary experimentation showed that 1 ml. of 0.005 per cent methyl orange solution is instantly decolorized by 21.9 μg. of chlorine. Since 1 ml. of 0.005 per cent solution contains 50.0 μg. of methyl orange, this yields a methyl orange-chlorine ratio of 2.28. The ratio of one molecular weight of methyl orange and two molecular weights of chlorine is 2.34, well within experimental error of the value 2.28. Inasmuch as methyl red and other azo dyes are bleached in acid

medium, it is logical to presume that the common azo bond is the locus of the reaction, and that the oxidation results in the disruption of the azo linkage.

$$(CH_3)_2NC_6H_4N = NC_6H_4SO_3Na + 2Cl_2 \rightarrow (CH_3)_2NC_6H_4NCl_2 + Cl_2NC_6H_4SO_3Na$$

Reagents

1. *Methyl orange stock solution (0.05 per cent).* Dissolve 0.5000 g. methyl orange dye in 1 liter of distilled water.

2. *Methyl orange solution (0.005 per cent).* Dilute the stock solution to the proper volume. The reagent has excellent stability.

3. *Dilute hydrochloric acid (5 N).* Dilute 428 ml. concentrated hydrochloric acid to 1 liter.

Procedure

Pipette 100 ml. of the sample into a white porcelain casserole. Add 2 to 4 drops of dilute hydrochloric acid. Then, with continuous stirring, rapidly titrate with 0.005 per cent methyl orange to the first pink color.

To convert into parts per million chlorine, substitute in the following formula:

$$\text{ppm. } Cl_2 = 0.04 + (0.217 \times \text{ml. methyl orange used}).$$

Effect of Various Factors on Reaction

Specific Acid Medium. Dilute hydrochloric acid alone supports a spontaneous reaction between chlorine and methyl orange. The presence of sulfuric, nitric or acetic acid delays the completion of the reaction by several minutes.

pH. Notwithstanding the fact that reaction velocities are equal at a pH of 2.0 and 4.0, a minimum of hydrochloric acid is recommended. A pH below 3.0 causes rapid fading of the end-point.

Temperature. Sample temperatures, whether 0° or 25°C., exert no effect on the reaction.

Interference. If the titration is executed with normal dispatch, interference from all oxidizing agents except manganic manganese and halogens in the elementary state can be effectively eliminated.

Ferric iron and nitrite up to 25 ppm., as nitrite, can be tolerated because of the protracted induction period required for reaction with methyl orange.

The titration of 0.5 ppm. chlorine dioxide (*7*), on the other hand, disclosed at the first end-point the presence of the 100 per cent excess free chlorine applied for the purpose of completely converting the sodium chlorite. The end-point faded swiftly, though, and it was possible to titrate all of the chlorine dioxide in 5 to 10 minutes, by resuming the titration after each discharge of color.

Effect of Chloramines on Methyl Orange

Minute traces of ammonia or its salts strongly inhibit the reaction between chlorine and methyl orange in hydrochloric acid solution. This fact was strikingly demonstrated in the laboratory and in plant experience.

At the time of this research, the Detroit, Mich., Dept. of Water Supply was employing free residual chlorination at one treatment plant and the chlorine-ammonia process at another plant. The chlorinated effluent combined ideally with methyl orange; the effluent of the chlorine-ammonia process (0.2 ppm. ammonia applied ahead

TABLE 1

Titration of 100 ml. Sample With 0.005 Per Cent Methyl Orange

Chlorine Added *ppm.*	Volume of Methyl Orange Decolorized			Deviation in Terms of Chlorine *ppm.*
	Calculated *ml.*	By Experiment *ml.*	Deviation *ml.*	
0	0	0	0	0
0.07	0.32	0.10	−0.22	−0.048
0.08	0.37	0.15	−0.22	−0.048
0.10	0.46	0.25	−0.21	−0.046
0.20	0.93	0.72	−0.21	−0.046
0.30	1.39	1.18	−0.21	−0.046
0.40	1.85	1.65	−0.20	−0.043
0.50	2.31	2.11	−0.20	−0.043
0.60	2.77	2.57	−0.20	−0.043
0.70	3.24	3.03	−0.21	−0.046
0.80	3.70	3.50	−0.20	−0.043
0.90	4.17	3.97	−0.20	−0.043
1.00	4.62	4.43	−0.19	−0.041
1.10	5.09	4.90	−0.19	−0.041
1.20	5.55	5.36	−0.19	−0.041
1.30	6.01	5.83	−0.18	−0.039

of pre-chlorination) failed to respond. The difference in reactivity could be attributed solely to the presence of ammonia, since the analysis of both effluents was conducted in precisely the same manner, 2 drops of 5 *N* HCl being added prior to titration.

Samples drawn from the distribution system served by the chlorine-ammonia plant showed a total chloramine residual of 0.45 ppm. by the ortho-tolidine method. A similar solution of 0.45 ppm. free chlorine would require a methyl orange titration of 1.9 ml. Less than 0.2 ml. of reagent, however, sufficed to produce in the chlorine-ammonia treated water an end-point which lingered for 10 minutes. The vanished pink color could be restored by adding an excess of 5 to 10 drops of reagent, after which the color would again slowly discharge over an interval of several minutes. This procedure of increment titration had to be extended over a period of 2½ hours before the full 0.45 ppm. dosage could be determined.

Synthetic chloramine solutions prepared from 0.2 ppm. ammonia and 1.2 ppm. chlorine followed an identical behavior pattern. Increasing the chlorine concentration failed to accelerate materially the reaction velocity.

Experimental Results

At the outset of this study, ammonia-free distilled water, Detroit raw and tap water, sodium hypochlorite, and elementary chlorine were all used interchangeably to discover the best combination, and also to note the individual effect of each variable. Repeated trials demonstrated that the success of the method was not contingent upon any single combination. Consequently, the majority of the experiments were conducted with elementary chlorine on Detroit raw and tap water. In every instance, parallel checks were run by the starch-iodide and the ortho-tolidine

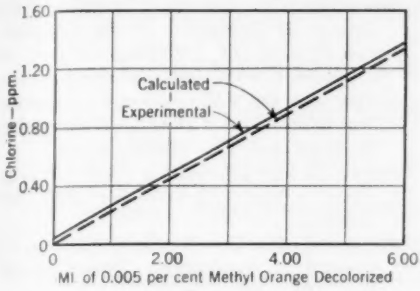

FIG. 1. Accuracy of Methyl Orange Titration

methods. Agreement was close in virtually all cases.

The points making up the broken line in Fig. 1 were plotted from the calculated values presented in Table 1. The points on the unbroken line, drawn from Table 1, were obtained by experiment. Both lines obey the equation $y = mx + b$, differing only in the values of the constant b. In the case of the calculated line the value of b is 0; for the experimental line the value of b equals 0.04. The value of m approximates 0.217 for the parallel lines.

The constant, b, highlights a pertinent fact with respect to the methyl orange-free chlorine reaction; namely, that the final 0.05 ppm. of chlorine in solution reacts sluggishly with methyl orange. Since this phenomenon occurs with uniform regularity, as the deviations in Table 1 indicate, proper allowance can be made for the relatively inert residual. This is constant over a chlorine interval of 0.07 to 1.3 ppm., contributing to the illusion that the reaction begins at a chlorine concentration of 0.04 ppm. Obviously, the constant loses significance when chlorine values soar above 1.0 ppm.

Stronger methyl orange solutions are desirable for titrations in the higher chlorine ranges. Suggested dilutions of the stock reagent are: 1 to 5, 2–5 ppm. chlorine; 1 to 2, 5–10 ppm.; undiluted, above 10 ppm. Corresponding compensation must be made in the mathematical formula when the stronger methyl orange solutions are employed. Table 2 presents values obtained with these respective methyl orange dilutions.

TABLE 2

Titration of 100 ml. Sample With Methyl Orange

Chlorine Added	Chlorine Found
ppm.	*ppm.*
3.0	3.1
5.0	5.1
10.0	9.9
25.0	24.5
50.0	49.0

Advantages of Methyl Orange

Perhaps the most effective way of emphasizing the virtues of methyl orange is by comparison with the sole titrimetric agent in current use, sodium thiosulfate.

First, insofar as water analysis is concerned, methyl orange is direct and chlorine-specific, whereas sodium thiosulfate measures the iodine electromotively displaced from potassium iodide by chlorine and chloramine. The starch-iodide method is indirect.

Second, methyl orange is a primary standard which retains its titer indefinitely. Sodium thiosulfate is not a primary standard and is notoriously susceptible to bacterial decomposition.

Finally, sodium thiosulfate necessitates the handling of large sample volumes in order to minimize experimental error. Methyl orange lends itself to the analysis of normal volumes, never exceeding 100 ml.

A concluding word of caution is, however, justified. Comparisons merely provide a criterion by which to judge

a reagent. It is folly to expect one reagent to satisfy the peculiar requirements of every occasion and situation. To the credit of methyl orange and sodium thiosulfate, it should be stated emphatically that they supplement rather than supplant one another.

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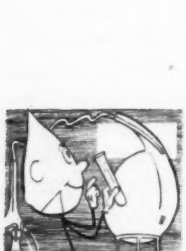

Characteristic Deficiencies of Water Distribution Systems

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IF a water distribution system is to meet recognized and fairly well established standards, it must be able to meet all critical demands, such as peak hour consumption and required fire flows, at all points throughout the system. Not only should it be capable of meeting these critical demands adequately, but it should have a reasonable degree of flexibility and reserve capacity. The National Board of Fire Underwriters advises that: "In general, reliable fire protection requires such duplication of all parts of a water system that, with such parts out of service as may reasonably be expected to be inoperative, the system will still be able to furnish the required fire flow."

Causes of Deficiencies

Deficiencies in a water distribution system may be the result of many different factors. Inadequate capacity of water mains is most commonly due to normal growth or change in character of the area being served. For example, if a main is required to carry 50 per cent more water than the quantity for which it was designed, a capacity that was adequate, with normal head loss, may become inadequate, with excessive head loss. Head loss with 50 per cent greater flow would become 212 per cent of the original design value, even with no change in the friction coefficient, C. If the value of C drops from a design value of 110 to 80, then the head loss would be further increased by 80 per cent, making the total head loss 382 per cent of the original design value.

Although a great number of deficiencies are the direct result of normal conditions of change with the passing of time, certain others are created by improper design or by the lack of any actual design.

Method of Determining Deficiencies

During the past ten years, the authors have had the opportunity to discover many distribution system deficiencies by the application of the Hardy Cross method of analysis in a variety of water utility systems. Although many of these deficiencies involved sanitary defects or structural hazards in the distribution system, a large number were concerned with deficiencies in performance from a hydraulic standpoint. It is these latter deficiencies which are to be discussed in this paper.

In making analyses of various systems, it has been found that the best procedure is, first, to analyze the existing system for known conditions which prevailed on some past maximum day and for which reliable operating records are available. Input into the system may usually be taken directly from water department records. Data on the operation of storage should

be obtained. All available recording pressure gage charts on the system should be secured for the particular period being studied.

After setting up the critical maximum-day conditions, as they actually existed, and after taking into account the physical characteristics of the system and the proper distribution of water usage, the analytical solution of the problem can be carried out by the Hardy Cross method.

These analyses of existing conditions constitute, in reality, a diagnosis of the deficiencies of the system. The results of a considerable number of such analyses form the basis for the subsequent discussion. In all instances, the particular deficiency cited is, in substance, a true presentation of an actual case. The geographical location of each deficiency mentioned is considered of no consequence here, since the same or similar deficiency may be found in any group of systems that may be under consideration.

A wide range of deficiencies will be cited, which relate to all phases of the distribution system from the source of supply to the ultimate consumer. It seems advisable, therefore, to set up four general groups: (a) deficiencies at the source of supply, (b) deficiencies in storage conditions, (c) deficiencies in the piping network, and (d) other deficiencies.

Deficiencies at Source of Supply

Case 1. Gravity Supply

The entire system in this city is supplied by a single gravity line from storage reservoirs located several miles from the business section. No storage is provided on the distribution system, with the result that the supply line must be capable of meeting all peak demands. Consequently, the supply line is overloaded during peak hours when the system demand approaches a rate of 50 mgd. Velocities are in excess of 7 fps.

All of these conditions constitute a serious deficiency in the source of supply. The high velocities and resulting low pressures make it impossible to meet adequately either the domestic demand or the required fire flow.

Case 2. Main Pumping Station

The system under consideration receives its supply from a pumping station located at the site of the purification plant. A reservoir well situated and of adequate size is provided on the system. The excessive head loss in the reservoir connection, however, causes the discharge pressure at the pumping station to be abnormally high during periods of replenishing storage at night. This rise in pressure in turn reduces the rate of output of the pumping units. In fact, one unit cannot be operated at all during this period of high discharge pressure, because of its low shut-off head. The maximum rate of pumping is also controlled by an established maximum discharge pressure, in order to stay within the safe operating limits of the discharge piping and valves.

Failure of a single trunk main leaving this station would cause all high-service pumping facilities to become virtually inoperative. This situation is created because of the lack of proper flexibility in the discharge header.

Case 3. Booster Stations

Booster Station A is located at the extreme end of the main service. During peak hours this station is required to deliver water at the rate of about 25 mgd. This quantity of water must be drawn directly from the distribution

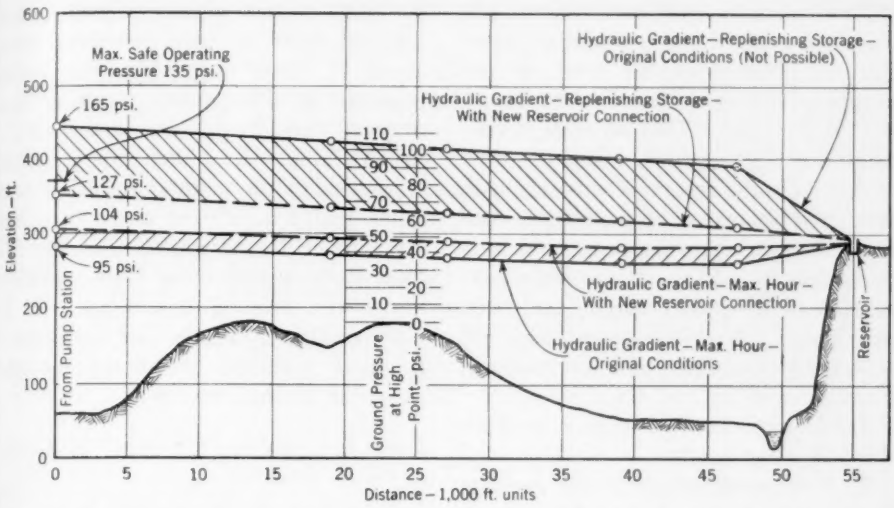
Max. Safe Operating Pressure 135 psi.
165 psi.
127 psi.
104 psi.
95 psi.
Hydraulic Gradient – Replenishing Storage – Original Conditions (Not Possible)
Hydraulic Gradient – Replenishing Storage – With New Reservoir Connection
Hydraulic Gradient – Max. Hour – With New Reservoir Connection
Hydraulic Gradient – Max. Hour – Original Conditions
From Pump Station
Ground Pressure at High Point – psi.
Reservoir
Elevation – ft.
Distance – 1,000 ft. units

FIG. 1. Effect of Inadequate Reservoir Connection on Full Equalization Operating Cycle

system of the main service, as there is no available storage.

The heavy draft from the main service produces excessively high velocities in the trunk mains serving the booster station. This situation in turn reduces the rate of output of the pumping units in the booster station, since the suction pressure drops about 20 psi. below normal. Another deficiency in Booster Station A lies in the fact that the failure of a single suction line would force the entire station out of service.

Booster Station B is intended to serve a high-level district during periods of peak demand in summer. Supply for the booster pumps is taken from ground storage. The booster district is isolated from the main service by a system of check valves which are intended to close when the booster station is in operation, thereby permitting the pressure to be maintained at the desired value. During periods of high demand, however, the station is unable to supply enough water to meet the demand within the district, so that the check valves cannot be closed. Thus, the entire purpose of the booster district is defeated.

Not only is the capacity of the booster station inadequate, but both the suction and discharge piping within the station are overloaded, even for the installed pump capacity.

Booster Station C. This station, a typical example of several in the same system, takes suction directly from the main distribution system network. Elevated storage is provided, but required fire flows cannot be met, due to insufficient pumping capacity.

Deficiencies in Storage Conditions

Case 4. Excessive Head Loss in Reservoir Connection

One of the most common deficiencies to be found in water distribution systems is that of a storage reservoir connected to the distribution network with mains of inadequate capacity. A specific example is shown in Fig. 1.

The hydraulic gradients indicated in this figure are those required to effect full equalization of the load on the pumping station during the maximum day of the year. Two separate conditions are shown: first, when the flow to and from the reservoir was seriously restricted because of an inadequate connection to the main network; and, second, after an additional reservoir connection of adequate capacity had been provided. The original conditions are shown by solid lines and the modified conditions by broken lines.

Inadequate storage mains produce the following results:

1. Full equalization of the load on the pumping station cannot be realized, because of the excessive pressure required during the night hours to replenish storage at the necessary rate.

2. Even if all piping and other auxiliaries were designed to handle the high pressure required at night, the pumps would fail to deliver water in sufficient quantity, since the operating pressure would exceed the shut-off head of all pumping units.

3. If the reservoir were permitted to respond as required to realize full equalization during the maximum hour, then the pressure on the high ground would drop below 40 psi. in the trunk mains.

4. A considerable waste of power would result from the type of operation shown for the original condition.

5. Since full equalization cannot be realized, additional pumping capacity, as well as additional trunk main capacity leaving the pumping station, is required to meet the increased rate of delivery during the day.

With the addition of the new reservoir connections of adequate capacity, all of the deficiencies cited have been removed. The minimum pressure at the control point of the system during the peak hour has been increased from about 37 to 47 psi. The maximum pressure at the pumping station has dropped considerably below the established value. In effect, the original capacities of the pumping station and trunk mains have been made adequate for a much longer period into the future than would have been possible under the original conditions. It is also possible under the new conditions to meet required fire flows directly from the storage reservoir.

Case 5. Failure of Storage to Operate as Intended

It has been demonstrated many times that a storage reservoir, although constructed on what appears to be an ideal point of high ground, will not always function as intended. Under certain topographic conditions, it is impossible fully to equalize the load on the pumping station during the maximum day, regardless of the reservoir capacity or the size of the connecting mains.

An actual hydraulic gradient prevailing during the maximum hour indicates (Fig. 2) that the ground pressure at the control point is less than 30 psi. in the trunk mains. If the reservoir were permitted to respond in such a way that full equalization on the pumping station could be realized, the pressure at the control point would drop below 10 psi. To prevent complaints of low pressure from the high areas, therefore, the rate of pumping is stepped up, and it becomes necessary for the pump station to deliver 90 per cent of the peak hour demand, instead of only 60 per cent, the rate required under full equalization. As a result, the pumping capacity, as well as the capacity of the trunk mains leaving the station, must be 50 per cent greater.

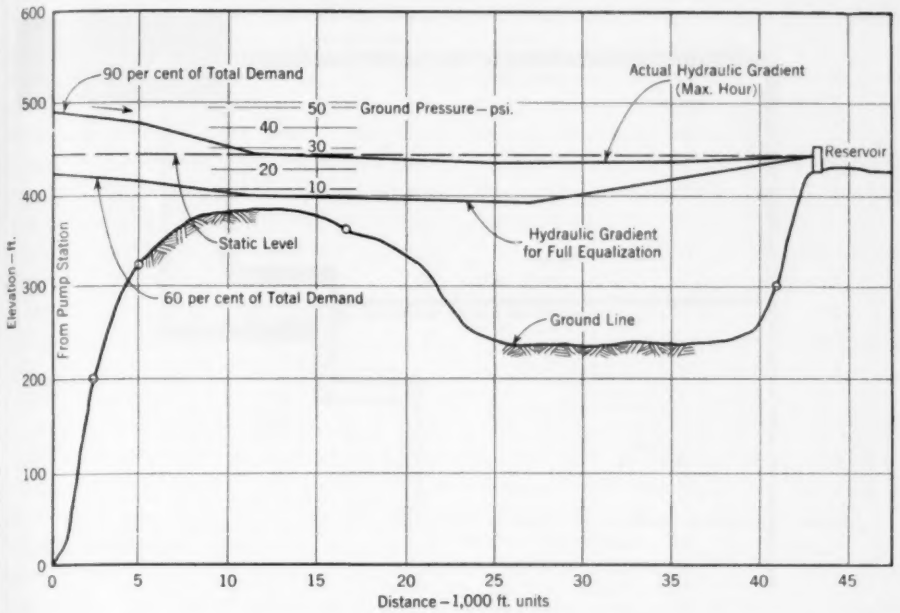

FIG. 2. Storage Operation With Pumping Station Near High Ground

Case 6. Other Reservoir Deficiencies

Another common deficiency in reservoir or elevated tank operation is demonstrated in Fig. 2. If the reservoir in this figure were replaced with an elevated tank, the conditions of full equalization of the pumping load could be met, provided, of course, that the trunk mains and tank connection were of adequate capacity. On the other hand, if the trunk mains approaching the low ground were inadequate to meet the morning peak in the valley area, the hydraulic gradient would sag very perceptibly at the point of high demand, and water would be drawn rapidly from storage. Thus the elevated tank might be completely emptied before the evening peak occurred in the residential area located on the high ground in the vicinity of the tank. In such a situation, of course, it would be advisable to provide control facilities to permit the elevated storage to be held in reserve to meet the evening peak.

A similar common deficiency in distribution system storage is that of two or more reservoirs or elevated tanks which are permitted to float, uncontrolled, on the same system. At least one example can be cited of a serious deficiency created by uncovered storage. Because of severe algae conditions during the summer months, this reservoir is operated through a weekly cycle. That is, the storage is practically depleted at the end of the week, at which time the reservoir is valved off and a heavy application of chlorine made. The reservoir is then permitted to fill on Sunday. When completely filled, the water contains the proper chlorine residual and may be released into the mains. Under the circumstances this weekly cycle of operation is considered necessary; but it is the

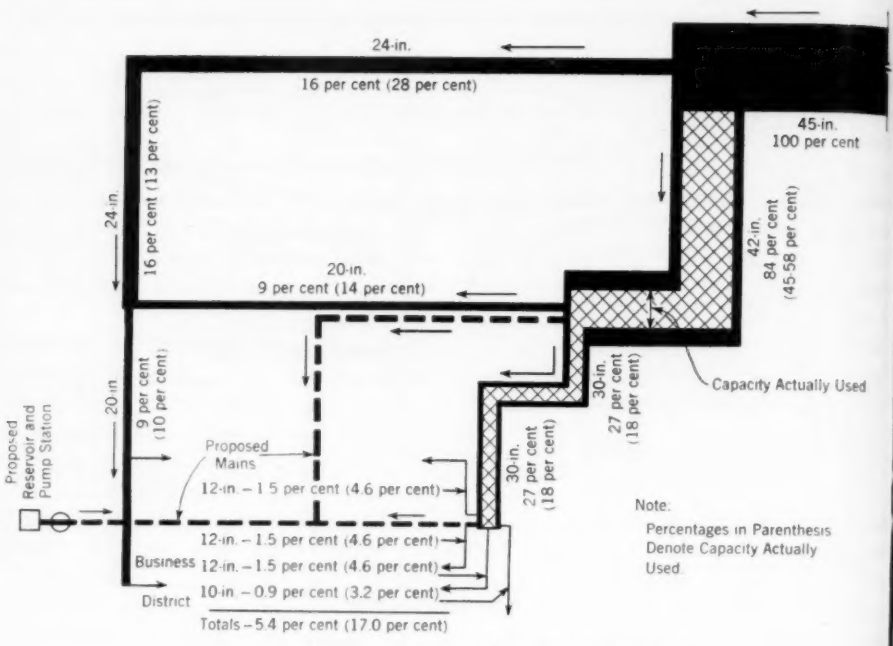

FIG. 3. Relative Carrying Capacities of Mains

intention of the management to provide a cover for the reservoir and eliminate the deficiency as soon as possible. In the meantime, a distinct hazard exists during the latter part of each week, when the reserve storage for fire protection is depleted.

Deficiencies in Piping Network

Case 7. Extreme Variations in Operating Pressure

Figure 3 will serve to demonstrate a number of common deficiencies to be found in the piping network. The system illustrated is supplied by gravity through a single 45-in. main from storage located about ten miles from the business district. No storage is provided on the distribution system so that the supply main must meet all peak demands. This line is already overloaded, especially during the late afternoon peak, when the velocity approaches 7 fps.

In Fig. 3, the width of line denotes the relative carrying capacity of each main, taking into account the diameter of the main and its *C* value. The relative carrying capacities are also based on the same head loss in ft. per 1,000 ft. for all mains shown. For example, taking the 45-in. main to represent 100 per cent capacity, the remaining mains would have the capacities shown in Table 1.

TABLE 1

Relative Capacity of Mains

Size *in.*	*C*	Total Capacity *per cent*
45	140	100
42	140	84
30	110	27
24	115	16
20	110	9
12	70	1.5
10	65	0.9

At the point where the 45-in. main terminates, it will be noted that the total of the relative carrying capacities of the 42-in. and the 24-in. mains combined is also 100 per cent. In other words, no restriction exists at this particular junction. At the point where the 42-in. main branches into the 30-in. and 20-in. mains, however, an entirely different situation will be observed. There the 84 per cent capacity in the 42-in. main is restricted to a total of 36 per cent in the two smaller mains which it serves. The reduction in capacity at this point is, therefore, 57 per cent. Similarly, at the terminus of the 30-in. main a further restriction is to be noted. At that point the reduction in relative carrying capacity is from 27 to 5.4 per cent, or a reduction of 80 per cent. The total reduction in relative carrying capacity from the 45-in. supply main to the three 12-in. and one 10-in. mains is found to be as much as 94.6 per cent.

It is not to be inferred that the relative carrying capacities should be constant throughout the system, since the total supply is gradually depleted as the mains approach the business section. The rate of take-off, however, does not warrant the two severe restrictions cited. Now, if the capacity actually used, as determined by analysis, is considered, another picture will be revealed, as indicated in Table 2.

TABLE 2

Load Carried by Mains

Size *in.*	Total Capacity *per cent*	Capacity Used *per cent*
45	100	100
42	84	58–45
30	27	18
24	16	28
20	9	14
12	1.5	4.6
10	0.9	3.2

It becomes evident from this tabulation that the two restrictions cause all other smaller mains shown to be even more severely overloaded than they would otherwise have been.

Hence, Fig. 3 demonstrates the following common deficiencies in the piping network:

1. Supply is derived through a single main with no reserve storage on the distribution system.
2. The capacity of some feeders is not fully utilized while others are severely overloaded.
3. Pressure in the business district drops from a maximum at night of about 75 psi. to slightly over 20 psi. during the peak demand.
4. Pressures are abnormally low throughout the system.
5. Low pressures in the high value district constitute a distinct fire hazard. Sprinkler systems are rendered ineffective on all except ground floors, and, even there, the efficiency of the system is seriously impaired.
6. Excessive velocities occur in all mains except the 42-in. and 30-in.
7. Severe restrictions to flow are evident at two separate locations.
8. The older mains are badly tuberculated.

The example shown in Fig. 3 represents conditions that develop rapidly in a city where the rate of growth is extraordinarily high. Although the city authorities have realized for some time the urgent need for improvements, it was physically impossible to carry them out during the war period. If the two bottlenecks were removed by the installation of new mains of greater capacity, the natural conclusion is that normal pressure conditions would be largely restored. The results of such a procedure are shown graphically in Fig. 4. It will be seen that if the ca-

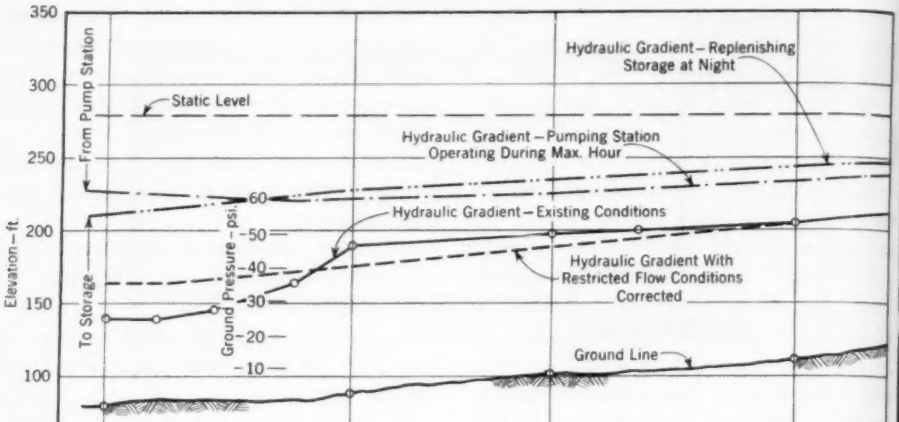

FIG. 4. Existing and Possible Future Pressure Conditions

pacities of the 42-in. and 30-in. mains were fully utilized, the hydraulic gradient for these mains would have a steeper slope than under the original conditions. The degree of improvement, therefore, would not be as great as might be expected, since all mains would still be severely overloaded. The pressure in the business district could be increased about 10 psi., which is only a very temporary improvement.

Other means of eliminating existing deficiencies, as well as providing for future growth, suggest themselves: (1) construction of a storage reservoir and pumping station, together with necessary supporting mains, on the opposite side of the business section from the source of supply (Fig. 3); (2) operation of this new pumping station only during peak hours of the summer months; (3) automatic operation of the station, so that the hydraulic gradient would be raised about as shown in Fig. 4, to maintain a minimum pressure of 55 to 60 psi. in the business section at all times; (4) operation to reduce the peak load on the supply main by about 35 per cent; (5) addition of a supply line in parallel with the present main as the hydraulic gradient declines in the future with further increases in demand, thus again raising the hydraulic gradient to the desired level in the business section.

Case 8. Roundabout Flow

A great many cases of roundabout flow have been observed. Some of the most striking examples are systems in which:

1. The distance of travel from source of supply to reservoir could be reduced from 12 miles to 7½ miles over a more direct route.

2. Water flows a total distance of 13,000 ft. to reach a point 1,000 ft. from the origin.

3. Supply to a residential section located only 2½ miles from source of supply is served by a roundabout route 12 miles long.

4. An old main of inadequate capacity between the pumping station and

the high-level district forced a large portion of the supply over another route twice as long.

Other Deficiencies

A number of additional deficiencies which have been observed may be mentioned:

1. The problem of providing adequate service to areas beyond the city limits is a difficult one to solve. Usually the water department does not have proper control over the nature and extent of water main construction in these areas. One large city is literally surrounded by a number of individual water districts, each of which has provided a very inadequate system even from the standpoint of service for domestic use. Fire protection supply, if it exists at all, is grossly inadequate. As the city limits are extended, these areas must be absorbed by the city system and the water system brought up to the proper standard.

2. Often the supply to large areas or to industrial developments is dependent on a single feeder.

3. Tuberculated mains create a potential deficiency in any distribution system. Rapid tuberculation renders main cleaning comparatively ineffective.

4. The arrangement and type of valves in the distribution system is of paramount importance. In at least one large system it has become the policy to install control valves of the cone or plug type to permit rapid closure when a main breaks. Experience has shown that if a break occurs in a trunk main 30-in. or larger in size, it is impossible to operate a standard gate valve against the full unbalanced head. By the time a number of gate valves have been closed or throttled, great damage has been done and service may be disrupted entirely for several hours.

5. Large areas, frequently, are not adequately provided with secondary feeders of proper size and arrangement to provide the necessary fire protection. The recommendations of the National Board of Fire Underwriters should be followed.

6. The existence of dead ends is a deficiency common to most systems in varying degrees. Dead ends should be cross-connected to eliminate stagnant water and, what is even more vital, to improve fire protection. For example, a dead-ended 6-in. main 1,000 ft. long will deliver only 28 per cent as much water at the extreme end as could be delivered to the same point, with the same head loss, if an equal supply were also available from the opposite direction.

Correction of Deficiencies

The deficiencies that have been discussed were determined for the most part by the Hardy Cross method of analysis. It should be pointed out also that trunk main surveys and fire flow tests furnish valuable information in the determination of system deficiencies.

Certain problems and the methods for their correction are self-evident; others, although they are recognized as problems, are obscure of solution. One very common fallacy in the correction of system deficiencies is to attempt merely to alleviate the existing situation, without considering future requirements. If the problem of correcting deficiencies is to be solved in a thorough and technically competent manner, requirements for a reasonable future period must also be considered. By making hydraulic analyses of fu-

ture conditions, including proposed improvements, guesswork can be reduced and the performance of new improvements evaluated while deficiencies in the existing system are eliminated. Any number of hypothetical cases may be solved and the best and most economical solution determined before a single dollar is spent on construction.

During the last few years there has been a very noticeable trend toward the realization that water distribution system improvements can be designed along sound engineering principles, much as are the other important elements of water works systems. It is hoped that water works superintendents will more generally recognize the value of keeping complete and accurate records of the performance of their distribution systems. Permanent recording pressure gage stations as well as metering stations should be established at carefully selected locations throughout the system. Records of the operation of storage should be kept at all times. With such performance data, the operating personnel will be able to anticipate deficiencies and have time enough to make the necessary system improvements before a critical situation develops.

Iron Salts as Coagulants

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SINCE the turn of the century, several different iron compounds have been used as coagulants in this country in the treatment of water supplies. Commercial ferrous sulfate (copperas), first used as a coagulant at Quincy, Ill. in 1902, is used in conjunction with lime in what is known as the lime and iron process. Since 1902 the use of "lime and iron" has increased gradually, particularly for the treatment of turbid river waters in the middle west. Chlorinated copperas (1) was first used by Hedgepeth and Olsen in 1927.

From 1928 until the start of World War II in 1941, the water works profession became greatly interested in the development and use of ferric coagulants. In addition to chlorinated copperas, two more commercial ferric coagulants (ferric chloride and ferric sulfate) have been developed. Since the outbreak of World War II, however, very little data have been published on the use of these iron salts as coagulants.

Coagulants Commonly Used

Alum (aluminum sulfate) is still by far the most widely used coagulant in the United States. A fairly close approximation can be made of the extent of use of iron salts as coagulants from "A Summary of Census Data on Water Treatment Plants in the United States" (2). This census represents conditions at the close of 1940, and, for some of the states, 1941. According to the U. S. Public Health Service, which compiled the data, there are approximately 1,688 water purification plants equipped with rapid sand filters in the U.S. They have a combined plant capacity of 2,980 mil.gal., and serve a population of 26.56 million people. Iron salts are used as coagulants by 88 plants having a combined plant capacity of 997 mil.gal., and serving a population of 4.33 million people. These plants are distributed in 25 states as far apart as Massachusetts and California.

The character of the water being treated with iron salts can be judged by the source from which it is obtained. The sources of water used by these 88 plants are given in Table 1.

Lime is used along with iron salts in 72 of the 88 plants, and alum is also used as a coagulant in 20 of the plants. In 40 plants, the water is softened.

The four iron salts used commercially in the United States as coagulants are ferrous sulfate (copperas), chlorinated copperas, ferric sulfate, and ferric chloride.

TABLE 1

Sources of Water Used by 88 Plants

Rivers	40
Wells	17
Lakes, Ponds and Impounding Reservoirs	19
Creeks, Brooks and Springs	12

Ferrous Sulfate (Copperas)

The material used in water plants consists of fine "sugar sulfate" crystals. It is a green crystalline salt readily soluble in water and contains about 100 per cent $FeSO_4 \cdot 7\,H_2O$. Shipments are generally made in bulk or in multiwall paper bags.

Chlorinated Copperas

Chlorinated copperas is made at the water purification plant by oxidizing ferrous sulfate with chlorine to form a solution of ferric sulfate and ferric chloride. This is done by mixing the aqueous discharge from a dry feed ferrous sulfate machine and a solution feed chlorinator. One lb. of chlorine is used for each 7.8 lb. of copperas, according to the following equation:

$$6\,FeSO_4 \cdot 7\,H_2O + 3\,Cl_2 \rightarrow 2\,Fe_2(SO_4)_3 + 2\,FeCl + 7\,H_2O$$

The chlorine is generally added in slight excess.

Ferric sulfate (Ferrisul, Ferri-Floc)

Anhydrous ferric sulfate contains not less than 90 per cent $Fe_2(SO_4)_3$, and the crystalline form not less than 60 per cent. It is a free-flowing globular salt, and the particle size should be such as to feed freely with reasonable accuracy in a dry feed machine. It is shipped in bulk and in multiwall paper bags.

Ferric chloride

Ferric chloride is normally available in 39 to 45 per cent solutions and is shipped in glass carboys, rubber-lined drums and rubber-lined tank cars.

Iron Salts as Coagulants

Solutions containing iron salts are corrosive, particularly ferric chloride and chlorinated copperas solutions. The equipment used to handle them should be made of rubber, glass, ceramic material or stainless steel. Granular iron salts should be stored in a dry place. If stored in a warm humid atmosphere, caking is apt to result. Kramer and Graf (3) found that if they specified and obtained for use at the St. Louis plants a copperas containing not less than 105 per cent (of theoretical) $FeSO_4 \cdot 7H_2O$, it would store without caking.

Solutions containing iron will stain floors, walls and equipment with which they come in contact. Careful housekeeping is required to prevent these unsightly stains when using iron salts. If activated carbon is not used, the sludge from basins and the wash water will impart the characteristic red-brown iron color to streams and other bodies of water into which they may be discharged. This may cause complaints.

Ferric sulfate does not go into solution readily, and special equipment is required to apply it successfully. For feeding ferric sulfate continuously, a dry feed machine plus a dissolving pot equipped with an agitator is required. The water ratio should be carefully controlled. Approximately two parts of water to one of ferric sulfate are required. A flow meter should be installed on the water line to make sure that the correct ratio is maintained, and the dissolving pot should be large enough to provide 30 minutes of detention time. The ground ferric sul-

TABLE 2

Optimum pH Range for Coagulation

Coagulant	*pH Range*
Aluminum Sulfate*	5.5– 8.0
Ferrous Sulfate	8.5–11.0
Ferric Sulfate, Ferric Chloride and Chlorinated Copperas	4.0–11.0

* Also effectively used in softening plants at pH values above 10.0

fate discharged into the chemical feed machine should be kept dry at all times.

The precipitate formed when iron salts are used as coagulants is a complex hydrous ferric oxide (4). The "floc" formed is generally referred to as "ferric floc." When using copperas (ferrous sulfate), lime must also be added, for it is only in the alkaline zone that the oxygen in the water will oxidize the iron from the ferrous to the ferric state, and form the desired insoluble "ferric floc." Ferrous iron is more soluble.

With the various coagulants there is an optimum pH zone in which a dense rapid settling "floc" will be formed in the shortest time. This optimum range varies with the type and nature of the water being treated, and can best be determined by jar tests. Certain zones have been set up which indicate approximately the pH range within which good coagulation can be obtained when using various coagulants. They are indicated in Table 2.

There are times when a poor "floc" is obtained with aluminum sulfate, even when the pH value is properly adjusted. Baylis (5) has found that in many cases when such a condition exists, silicates have aided coagulation. This applies to a lesser extent to ferrous sulfate, but silicates were found to be of little value when used with ferric salts. Similar conclusions were reached by Lordley and Smith (6) following their studies in the use of sodium silicate.

It is claimed that iron salts produce a faster forming, denser, quicker settling "floc" than alum. This is particularly true during the winter months when the temperature of the water is low. The "ferric floc" is not so readily broken up.

Due to the wide pH range over which the "ferric floc" is formed, iron salts have proved particularly valuable in treating colored or turbid impounded waters containing manganese. Manganese is precipitated at a pH value over 9.0. Iron salts may be used for the treatment of colored waters in the acid range at a pH value below 5.0. The "ferric floc" does not redissolve at high pH values, and thus residual color coagulated in the acid zone does not redissolve when the filtered water is treated with lime for corrosion prevention. Iron salts may also be used in the treatment of hard, colored or turbid waters in the alkaline range.

Use of Iron Salts in Plants

Before using iron salts on a plant scale, careful laboratory jar tests should be made to make sure that proper coagulation will be obtained. Caution should be used when treating waters containing excessive quantities of organic matter with ferric salts to make sure that the trivalent ferric ion will not be reduced to the more soluble bivalent ion.

Copperas (lime and iron) is used to treat the turbid river waters at St. Louis, Mo., New Orleans, La., Cincinnati, Ohio, and a number of other middlewestern cities located in the Mississippi River drainage area.

Chlorinated copperas was used at Elizabeth City, N.C. (1), and at Chickasaw, Ala. (7, 8), to treat a soft, highly

colored water. At Elizabeth City the water was first coagulated with chlorinated copperas in the 4.2–4.7 pH range. Sodium aluminate was used as a secondary coagulant, at a pH range between 5.5 and 6.5. At Chickasaw, lime is added to combine with the dissolved iron left after the iron color complex is formed at a low pH value. Prechlorination is practiced, and sufficient chlorine added to maintain a residual chlorine content on top of the filters. This is to keep the iron in the ferric state and prevent its reduction to a ferrous state during the settling period.

Providence, R.I. (9, 10), has used lime and iron, lime and chlorinated copperas, and lime and ferric sulfate to treat a soft, moderately colored water containing manganese. The "ferric floc" was formed at a pH value of 9.7–9.8. Good results were obtained with all three coagulants, ferric sulfate being the best of the three. Special equipment was installed for feeding the ferric sulfate. No difficulty was experienced with bulk storage of the ferric sulfate.

At Albany, N.Y. (11), lime and iron, and ferric sulfate and lime have been used to treat a soft water from a large impounding reservoir in order to remove manganese. The treatment is seasonal. Better color removal was obtained with ferric sulfate than with lime and iron. Difficulty was experienced in flocculating the iron salts during the period of fall turnover. During this period, a poor effluent was obtained. This was attributed to the reduction of the "ferric floc" to the ferrous state in the presence of organic matter. No difficulty was experienced with the bulk storage of ferric sulfate.

At Richmond, Va. (12), chlorinated copperas has been used for a number of years to treat successfully a soft, turbid river water containing industrial wastes. Pre-chlorination is practiced. To obtain the best results during periods of descending turbidity, alum is also used (10 to 15 per cent by weight of the main coagulant). When the temperature is low, careful control of the coagulant dose is required. Under these conditions, it has been found that the addition of 10 to 20 lb. per mil.gal. of burnt lime has a remarkable effect in widening the quantity limits for coagulation.

At Dallas, Tex. (13), lime and iron, and lime and chlorinated copperas were used to soften and remove the turbidity from a water obtained from a large lake. An appreciable saving (approximately $4,000 per year) was made when lime and chlorinated copperas was used in place of lime and iron. Alum is used as a secondary coagulant. It is claimed that by improved plant design the use of a secondary coagulant could be eliminated, saving an additional $2,000 per year.

Professor Charles Gilman Hyde (14) reports the successful use of ferric chloride in the treatment of a colored water at the Wilmington plant in Los Angeles, and in the treatment of well waters at the two municipal water plants of Beverly Hills, Calif. At Beverly Hills, color and hydrogen sulphide are removed, and the water is softened as well.

At Hammond, Ind. (15), both chlorinated copperas and ferric sulfate have been successfully used to treat a Lake Michigan water containing industrial wastes. Due to the presence of phenols and other industrial wastes, large quantities of activated carbon are also used. Pre-chlorine-ammonia treatment is also practiced. It was found that use of ferric salts sharply reduced the mud ball count in the filters, thus

TABLE 3
Analysis of Sulfate of Alumina

	Per Cent
Insoluble Matter	6.39
Aluminum Oxide (Al_2O_3)	17.16
Iron Oxide (Fe_2O_3)	0.40
Sulfuric Acid	45.25
Free Aluminum Oxide (Al_2O_3)	1.70

reducing the coagulant cost. No lime was used.

Ferric sulfate has been used to treat Lake Michigan water at Racine, Wis. Chlorine-ammonia pre-treatment is also practiced. No lime is used.

Comparison Coagulation at Milwaukee

A new water purification plant was placed in operation in Milwaukee, Wis., in July 1939, using Lake Michigan as the source of supply. After using sulfate of alumina as a coagulant for one year, it was decided to investigate the use of ferric compounds for treating this supply. Two commercial brands of ferric sulfate were available—"Ferrisul" and "Ferri-Floc." Jar tests were made in the laboratory before using ferric sulfate on a plant scale. This investigation was made during June and July, 1940.

The water supply is taken from a submerged crib in Lake Michigan 6,565 ft. from the shore at a depth of 67 ft. There are two sets of basins at the Milwaukee plant. When operating normally, half of the supply is pumped to the north, and half to the south. The mixing and settling basins in each half of the plant are identical in size and design. By inserting stop plates in the settled water duct, it is possible to divide the plant into two equal sections.

Aluminum sulfate was being used, but it was decided to treat only one half the supply with alum and use ferric sulfate for the other half. In this way a direct comparison could be made of the different coagulants, as the raw water mixing and settling times would be the same in each half. A minimum carload (20 tons) of each of the two coagulants—Ferrisul and Ferri-Floc—was purchased. A chemical analysis of the alum is given in Table 3, and, of the Ferrisul and Ferri-Floc, in Table 4.

The designed capacity of the Milwaukee plant is 200 mgd. when the filters are operated at a rate of 2 gal. per sq.ft. One hour of mixing plus 4 hours of settling are provided at the designed rate of flow. The mixing basins are equipped with Dorr flocculators, and the settling basins are two-decked. The water flows from the mixing basin through the lower half of the settling basin, through an opening in the upper deck, and then back through the upper half of the basin in a reverse direction to the filters. There are 32 filters, each having a normal capacity of 6.25 mgd. The filters are equipped with surface wash systems.

Chemicals used in treatment are applied to the 84-in. diameter raw water

TABLE 4
Analysis of Ferric Coagulants

	Ferri-Floc—%	*Ferri-sul—%*
Insoluble Matter	6.83	4.60
Ferric Sulfate ($Fe_2(SO_4)_3$)	67.10	89.69
Ferrous Sulfate ($FeSO_4$)	0.79	0.65
Free Sulfuric Acid	3.58	0.26
Other Sulfates	5.18	3.53
Free Moisture	3.71	1.27
Water Crystals	12.91	——
Total	100.00	100.00
Water Soluble Ferric Iron (Fe)	18.75	24.81
Water Soluble Ferrous Iron (Fe)	0.29	0.24
	19.04	25.05

TABLE 5

Chemical Doses, lb./mil.gal.*

Rate, lb./mil. gal.:		Run No. 1 Alum, 40 Ferrisul, 30	Run No. 2 Alum, 55 Ferrisul, 40	Run No. 3 Alum, 70 Ferrisul, 50	Run No. 4 Alum, 70 Ferri-Floc, 50
Dates:		June 12–21	June 22–26	June 27–30	July 19–26
Hours Run:		240	120	96	168
Amount Treated, *mil. gal.*	alum	473	206	168	470
	iron	472	201	168	468
Cost per mil. gal.	alum	$0.41	$0.56	$0.71	$0.71
	iron	$0.41	$0.54	$0.68	$0.55
Carbon, *lb./mil.gal.*		2.4	4.0	14.9	4.7
Chlorine, *lb./mil.gal.*	pre-	3.4	4.2	4.4	3.8
	post-	1.20	1.18	1.16	1.18
Ammonium Sulfate, *lb./mil gal.*	post-	1.53	1.35	1.50	1.48

* Alum, iron, carbon and pre-chlorine were applied to the raw water pipelines between pumps and mixing basins; post-chlorine and ammonium sulfate dosages were applied to combined effluent from north and south basins after filtration.

pipelines between the pumps and the mixing basins. A quick mix of from 3 to 10 minutes, depending on the rate of pumpage, is provided in the raw water pipelines. A number of 90-deg. bends in these lines aids mixing. During the investigation, chlorine, activated carbon and either alum or ferric sulfate were used. The same chlorine and activated carbon doses were applied to each pipeline.

During the season at which these tests were conducted, the turbidity is generally low. The water is free from color, iron and manganese, but does contain a varying number of microorganisms which may or may not cause trouble by producing tastes and odors. The raw water is moderately hard (approximately 130 ppm.), has an alkalinity of about 110 ppm., and a pH value of about 8.0. The total solids average about 145 ppm., calcium 34 ppm., magnesium 11 ppm., sulfates 20 ppm. and the chlorides 3.5 ppm. There is very little change in the mineral composition from year to year.

Sufficient coagulant is applied during the summer season to prevent a too rapid clogging of the filters by microorganisms. When the filter runs drop below 30 hours, the coagulant dose is increased. By using enough coagulant to maintain a minimum filter run of 30 hours, it has been possible to supply water at a maximum rate during the peak summer sprinkling load without drawing down the water in the clear well below a fixed safety level.

At the time the tests were run, the costs of the three coagulants delivered to the plant were:

	Cents per pound
Aluminum sulfate	1.02
Ferrisul	1.355
Ferri-Floc	1.105

TABLE 6

Raw Water Averages

	Run No. 1	Run No. 2	Run No. 3	Run No. 4
Temperature, °F.	47.8	44.4	47.4	44.2
Turbidity, *ppm.*	0.5	1.4	2.3	0.7
Alkalinity, *ppm.*	110	110	110	110
pH Value	8.17	8.08	8.06	8.13
Micro-organisms (standard units)	597	688	728	642
Residual Chlorine,* *ppm.*	0.21	0.26	0.26	0.23

* After pre-chlorination.

TABLE 7

Applied Water Averages (Top of Filters)

		Run No. 1		Run No. 2		Run No. 3		Run No. 4	
Rate, lb./mil. gal.:		Alum 40	Ferrisul 30	Alum 55	Ferrisul 40	Alum 70	Ferrisul 50	Alum 70	Ferri-Floc 50
Turbidity, *ppm.*		0.4	0.6	0.6	0.6	0.7	0.9	0.6	0.6
pH Value		7.88	7.85	7.76	7.72	7.72	7.70	7.59	7.64
Residual Chlorine, *ppm.*		0.07	0.07	0.09	0.09	0.08	0.08	0.07	0.07
Micro-organisms	Standard Units	195	162	152	159	62	101	738	73
	Per Cent Reduction	66	72	77	77	90	84	79	89

The present contract price for alum is 1.175¢ per lb.

After completing the preliminary jar tests, it was decided to adjust the doses of the iron salts and alum used on a plant scale on the basis of cost. A dose of alum which it was known from previous experience would produce a satisfactory effluent was used. The dose of iron salts was then adjusted so that the costs of the two coagulants being compared were approximately equal.

At the time the investigation was made, the threshold odor in the raw water was low, varying from 1 to 3, with the average under 2. The average coliform index in the raw water during the tests was less than 60 per 100 ml.

A water of excellent quality was produced using all three coagulants. The plant effluent was clear (turbidity less than 0.05 ppm.), colorless, had a threshold odor of 2 or less, and a coliform index of zero. The Ferrisul-treated filter effluents had a maximum iron content of 0.023 ppm., and an average of 0.012 ppm. The Ferri-Floc-treated filter effluents had a maximum iron content of 0.041 ppm., and an average of 0.016 ppm.

Conditions during the tests and the results are shown in Tables 5 to 8. Due to different mixing and settling times and filter rates, it is not possible

TABLE 8

Filter Data

Rate, lb./mil. gal.:	Run No. 1		Run No. 2		Run No. 3		Run No. 4	
	Alum 40	Ferrisul 30	Alum 55	Ferrisul 40	Alum 70	Ferrisul 50	Alum 70	Ferri-Floc 50
Mixing Time—*hours*	2.15	2.14	2.57	2.52	2.44	2.42	1.53	1.53
Settling Time—*hours*	8.59	8.57	10.28	10.08	9.75	9.70	6.13	6.13
Gallons Filtered— *mil.gal.*	472	473	201	206	168	168	470	468
mgd.	47.2	47.3	40.2	41.1	42.0	42.1	67.1	66.9
Filter Rate—*avg. mgd.*	90	90	100	100	100	100	120	120
Filter Run—*hours*	41.9	52.9	44.8	57.8	75.1	79.4	32.1	33.8
Gal./ft. Loss of Head/sq.ft. Sand	532	685	636	816	1065	1114	584	607
Number of Washes	57	47	20	13	9	9	57	57
Wash Water—*mil.gal.*	11.40	9.70	4.20	2.86	1.80	1.98	11.40	13.11
Wash Water—%	2.4	2.0	2.1	1.4	1.1	1.2	2.4	2.8

to compare the two iron coagulants directly. The rate of pumpage was about 50 per cent greater when Ferri-Floc was used. Larger coagulant doses were required at the higher rates of consumption, and the Ferri-Floc tests were therefore of shorter duration. The total quantities of Ferrisul and Ferri-Floc used during the tests were approximately the same, about 20 tons.

The iron salts were discharged directly into the weigh hoppers through chutes. No difficulty was experienced in dissolving and keeping the iron salts in solution in the stainless steel dissolving tanks which had been provided with each alum dry feed machine at the Milwaukee plant. It was difficult, however, during the humid weather to keep the iron salts feeding continuously in correct quantities. The iron salts caked on the endless rubber feeding belts which had to be cleaned at intervals of from 15 to 30 minutes. This condition could probably be corrected by using metal belts, or by installing air conditioning equipment in the cabinets of the dry feed machines.

Slightly longer filter runs and better micro-organism removal in the settling basins were obtained with the iron salts. The differences are not great, but do indicate, under the conditions existing when these plant tests were made, that Ferrisul or Ferri-Floc could be used in place of alum at the Milwaukee plant without increasing the cost of coagulant, and still provide a plant effluent of the same excellent quality. At the time the tests were run, the authors did not feel that there were enough differences in the results obtained to warrant changing the equipment so that a ferric coagulant could be used continuously.

Acknowledgment

The authors wish to thank Mr. McCarthy and Mr. Cowing of the Monsanto Chemical Company, from which they obtained the Ferrisul, and Mr. Howland and Mr. Shelton of the Tennessee Corp., from which they obtained the Ferri-Floc, for their splendid cooperation at the time these tests were made.

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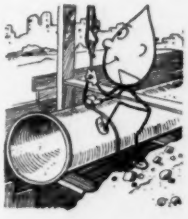

Foundation Treatment

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Presented on May 9, 1946, at the Annual Conference, St. Louis, Mo.

EVERY engineering and architectural structure must be built on a foundation that is an integral part of the terra firma of our planet. If every structure were built on what was known to be solid rock, there would be little need for foundation exploration or treatment. When locations are dictated by economic or geographical considerations, however, such stable material may not be available in the vicinity. If a general location has been established on the basis of the policies to be pursued by the prospective operator, an even more intensive search for the best possible exact site must be inaugurated. It is in this phase of the project that foundation exploration plays its part in sound construction.

Foundation Exploration

Too often prospective owners fail to spend sufficient money and effort in foundation investigation, thus committing themselves to a short-sighted economy which may often cost them far more than their immediate savings. If the work is simpler than the inadequate investigation indicated, the contractor is overpaid; if it is more difficult, the contractor may later sue for additional compensation due him as a result of unforeseen foundation problems not disclosed in the invitation to bid.

Lack of adequate foundation data may also increase the cost of a project by making it necessary to redesign a structure after the foundations have been exposed. Particularly is this true where work has been started after only a hasty investigation by inexperienced designers. It is an unusual foundation, indeed, that can be sounded by widely spaced exploration holes; yet in at least one instance construction of a large irrigation and power dam was begun on the basis of findings from exploration holes 400 ft. apart. At the most costly period of construction of that project, work had to be suspended while more foundation data were determined; and, at length, the entire project had to be redesigned. The total cost, including not only the expense of the false start and of the new structures, but the compensation for the idle time of the contractor, was of course tremendous.

The dangers of placing structures on soft foundations, such as hard pan, clay, shale, sand and gravel, have been recognized for a considerable length of time, but the hazards involved in dealing with foundations in rock are not generally known. Too often it is assumed that where rock is available at a reasonable depth, the foundation problem is solved. Nothing could be further from the truth—particularly where hydraulic structures are involved. The failure in 1900 of the dam across the Colorado River at Austin, Tex., from basic foundation undercutting, and the foundation leakage at the Hales Bar

Dam, Tenn., ever since its completion in 1913, afford convincing proof of this fallacy.

Available to designing engineers are the following methods of foundation exploration: test pits; shot or calyx drill holes of 3, 6, 8, 10, 12, 36, 48 in. and even larger diameters; diamond drill holes up to 3 in. in diameter; various types of percussion drilling by cable tool rigs or air tools; wash borings; augur borings; and rotary drilling. Of these, test pits or drillings give by far the best information in earth, as undisturbed samples can be taken at regular intervals and changes of formation can be studied with a split-tube sampler. In rock, there is no substitute for diamond drilling in small diameters and shot or calyx drilling in large diameters.

Foundation Treatment

Once adequate data are available, the question of proper foundation treatment must arise. Little can be said generally, except that each foundation is a problem in itself, which requires a "tailor-made" solution.

In the past twelve or thirteen years, great strides have been made in the development of foundation treatment methods, particularly on large government hydroelectric projects such as those constructed by the Tennessee Valley Authority, the Bureau of Reclamation and the Army Corps of Engineers. Many of the new methods and devices for grouting and for soil analysis were developed by the engineering staffs of these governmental departments.

Cement Grouting in Rock

In cement grouting in rock, a hole pattern is laid out to fit the particular

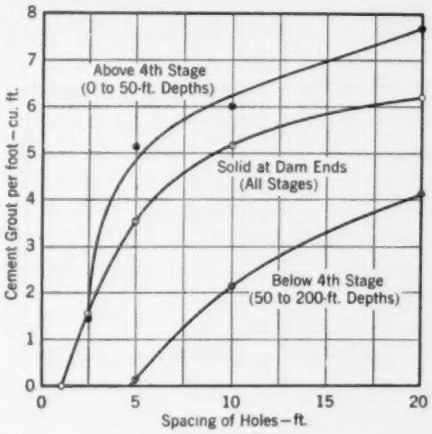

FIG. 1. Typical Grout-Consumption Curves

structure. For example, under a large dam, shallow holes, 20–30 ft. deep, may be drilled on diamond or double diamond patterns for consolidation or bearing grouting. These holes start from wider spacing and gradually narrow down to closer centers. For bearing only, under slab bearing structures, holes are often drilled by air tools such as wagon drills. These holes are carefully washed out with air and water, and as far as possible connecting channels between holes are established and cleaned out. This is necessary because of the seam clogging tendency of percussion drills. A pipe nipple is then grouted into the top of these shallow holes, and spud connections from grout pumps are made. These holes are also grouted under low pressure from the top only, to prevent heaving of the rock. With this layer of consolidated rock available up to surface level, diamond drill holes are penetrated through the layer into the deeper reaches of the rock for leakage prevention by high-pressure grouting. This also follows a given pattern of spaced holes, gradually being reduced in spacing until an apparently watertight curtain has been

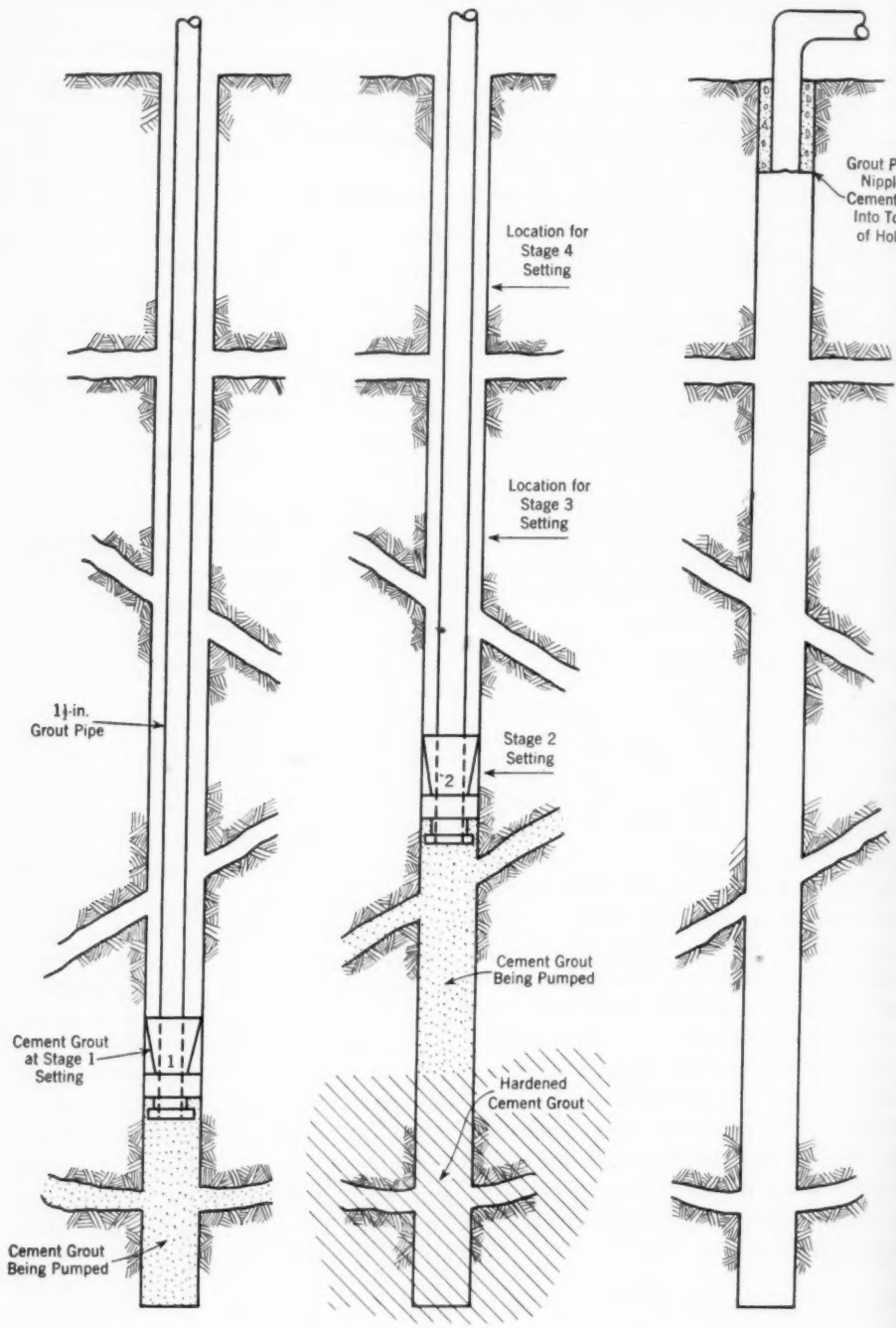

FIG. 2. Grouting by Stages and by Using a Single Setting

established. As spacing becomes closer, the amount of grout taken per foot of hole becomes less. The amount of grout taken and the pressures developed are indicative of the adequacy of the work (Fig. 1).

All cement grout in rock should be pumped by piston-type, slush-fitted pressure pumps which have removable cylinder liners and rubber pistons. Air-operated pumps are generally used to provide flexibility. Grout is started at very thin mixes; 2 cu.ft. of water to 1 sack of cement. Wherever a hole can be grouted to refusal with this mix it is done, but there is no hesitancy in thickening the grout progressively if required to the thickest consistency the pump will handle, that is from 0.5 to 0.6 cu.ft. of water per bag of cement. Even then it is sometimes necessary to limit the "take" of a hole in the interests of economy, and return to it the next day.

No hole in rock is ever considered thoroughly grouted until it refuses under application of a thin mix of about 1.6 consistency. In many cases previous refusals have been obtained with thicker mixes. Pressure is then held on the setting until grout takes its initial set. Thereafter the hole is jetted out and regrouted with a thinner mix. If it is not feasible to jet out a hole, the hole is reamed the following day and regrouted with the thin mix. This procedure is continued until a setting refuses to take the 1.6 grout. Refusal means practically no take of grout for 1–2 hours at predetermined pressure, with the return line on. (All holes to which the pressure has to be regulated have a return line to the grout machine.) Pressure in holes is predetermined depending on hole depth and character of material, usually at about 1 psi. per ft. of depth. The return line valve is then regulated to maintain this pressure on the hole.

Holes in rock may be "stage" or "step" grouted. Only in shallow and comparatively low-pressure holes is the entire hole grouted from the top in one setting with a nipple cemented in place. In all other instances grouting is done through a transmission pipe, usually $1\frac{1}{2}$ in. in diameter, with a quick-breaking packer at the bottom. This packer can be set at any level for water or dye-testing a hole, and can also be used for cement or asphalt grouting.

Stage Grouting

In stage grouting the packer is set progressively from the bottom of the hole to the top in approximately 10–20 ft. increments, each stage being grouted to refusal. In an application of this method at Dix Dam in Kentucky, asphalt was pumped into a leakage area about 350 ft. down and cement grout in stages was pumped above this setting. Similarly, a large part of the 155,000 cu.ft. of cement grout at Hales Bar Dam was applied by this process.

The first two sections of Fig. 2 illustrate the stage method of grouting; the last section shows the single-setting method with the nipple cemented in place at the top.

Step Grouting

In step grouting, the stage process is reversed. A hole is drilled to a depth of its first increment—probably to a seam or a point at which it loses water—or the maximum predetermined increment. It is grouted to refusal in accordance with previously described standards (Fig. 3), and then reamed through this depth down to another in-

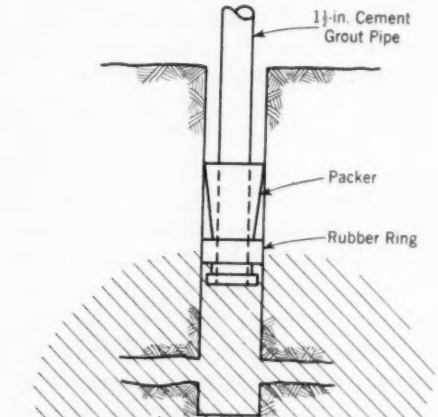

FIG. 3. First Increment, Step Grouting

cremental depth, and the process is repeated (Fig. 4). Where leakage may be expected at low levels, such as some of the areas at Hales Bar and Great Falls, Tenn., this system presents an advantage, since all the upper area is impregnated, and the leakage seam can be dealt with in the manner that best suits its characteristics.

Considerable step grouting was employed at TVA's Chickamauga and Fort Loudoun Dams, Tenn. An adaptation of this method was used at the Rio Negro project in Uruguay, where on numerous occasions later applications at the same setting took more grout than the former ones. This phenomenon has not yet been satisfactorily explained, but the grouting methods used were not exactly comparable with those in use in the United States.

Practically all rock grouting, if at all possible, should be done with cement only. The use of sand in the mixes is badly out-of-date. Pushing mortar through water in a hole has exactly the same effect as pushing

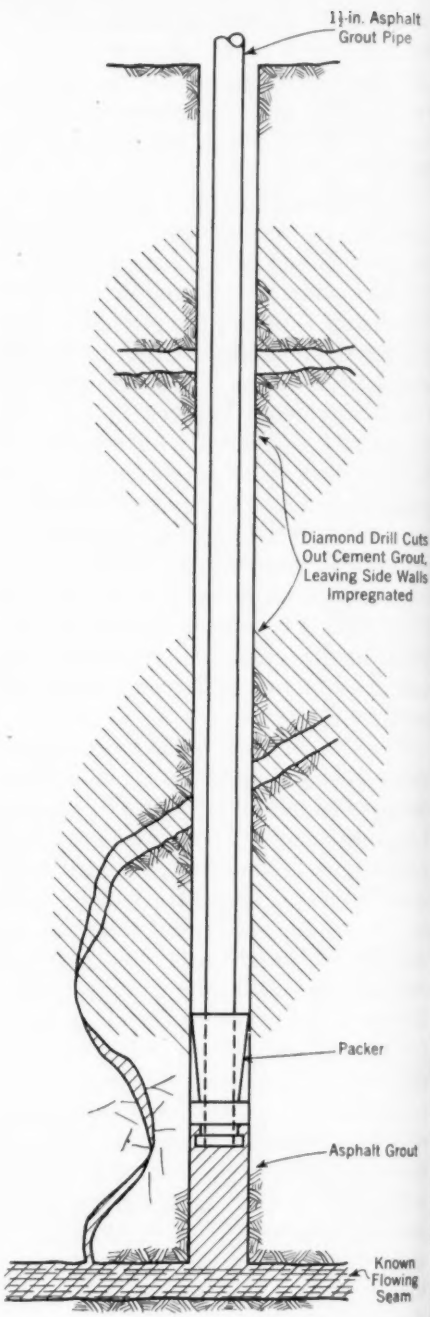
1½-in. Asphalt Grout Pipe
Diamond Drill Cuts Out Cement Grout, Leaving Side Walls Impregnated
Packer
Asphalt Grout
Known Flowing Seam

FIG. 4. Step Grouting to Completion

water through a wet mortar; the result is segregation. Unless grouting with sand-cement mortars can be done by tremie under atmospheric pressure until a hole is full, it is not to be recommended. Results are dubious, and there is not even the apparent saving one would expect, for mortar grouts cannot be pumped satisfactorily or economically with piston-type pumps. Also, although sand is cheaper, the special handling and labor involved to make up these mortars offsets any saving in cement.

The use of admixtures for controlling the time of setting of cement is quite another matter. In certain places quick-setting cement grouts are desirable and should be used; their efficacy has been well demonstrated at Great Falls. Numerous commercial products are made especially for this purpose, and there are such chemicals as calcium chloride and sodium silicate, either of which produces quick-setting qualities in cement. Mixtures of "Lumnite" and portland cement in various proportions may also be used, depending on the speed of set desired. Calcium chloride is used principally, a brine of known concentration being prepared and added to the mix water. Sets as fast as 90 seconds can be produced this way, or retardation can be secured by adding more water.

Cement Grout in Soils

Cement grouting in sand and gravel can be done fairly efficiently, but its effectiveness is in the ratio of the size of the voids between particles. In the fine materials, for example, cement "grouting" is a misnomer. It would be more aptly called cement "consolidation," for this is about all that can be expected. This work is done by sinking a 2- or 2½-in. pipe to the desired depth, cleaning it out and raising it a predetermined increment, usually about 2 ft. Cement grout lines are then hooked to the pipe and by alternate pressure grout applications to refusal and jacking of the pipe, the grout is forced through the pipe into the material from the bottom of the hole to the top. Quite obviously, the effectiveness of this work also depends on the pressures used and the spacing of the holes. Very close spacing is required for maximum results.

A large amount of cement consolidation work was carried on at Kentucky Dam and at Chickamauga and Watts Bar. In the latter two instances, considerable experimentation was done with clay cements, using 1 part cement to 2 parts clay for consolidation. This clay use unquestionably saves money if used in large enough quantities. The plant necessary to mix it is complicated, however, since the clay has to be dried, to eliminate all lumps, and then screened. Experience dictates that it must also be premixed with water before combining with the cement slurry for greatest effectiveness. Thus, unless a large volume of repetitive work of this sort is in prospect, it is usually advantageous to use cement alone.

Cement consolidation in soils should not be looked upon as a cure-all. It will stabilize the soil, if the soil contains sufficient voids to absorb some cement, and it is inexpensive to apply. There are soils, however, for which the use of bentonite, clays and other mixtures can work to best advantage. Again, each problem requires a prescription all of its own.

Asphalt Grouting

For leakage correction in rock, asphalt grouting can be very effective if

FIG. 5. Great Falls Dam Leak No. 5 Before Grouting

FIG. 6. The Same Leak After Grouting

applied correctly. It is not considered reliable as a bearing material, although some leaks have been plugged with spectacular success by the use of asphalt grout. Great Falls, Tenn., is the prime example of what can be done with asphalt. The work there is over 2 years old and is holding up very well. Figure 5 shows Leak No. 5 at Great Falls before asphalt grouting; Fig. 6 shows the same area after treatment. The whitish substance appearing to trickle down the ledges is not water but solidified cement. The cofferdam around the East Norfolk Dam on the Raquette River in north central New York was a troublesome water producer before asphalt grouting sealed off its leakage so that construction could proceed behind a dry cofferdam. Another example is Dix Dam in Kentucky.

Asphalt is most effective in labyrinthal seams where effective stops against movement are available after it has frozen. The melting point of asphalt should be so high that it will remain frozen at medium temperatures, and its flashpoint should be very high, to prevent fires. Melts at about 185–190° F. are commonly specified and flashpoints of 450–475° F. are usual. The specific gravity is about 1.0, although both lighter and heavier asphalts are used for specific applications.

The asphalt is generally heated to about 400–450° F. and then pumped through 1½- or 2-in. pipe with a ball valve piston-type boiler feed pump, air-operated and suitable for pumping asphalt. Other types of pumps can also be used, but this type is peculiarly well adapted to grouting work under pressure. If heating and pumping capacities are sufficient, there is no need for heating elements, although such expedients as electric hot wires and steam have been used in the past. Heating and pumping capacities are now considered far more necessary to successful execution than heating elements in the hole. Asphalt in earth grouting has not been tried to the best of the author's knowledge. In a coarse gravel it probably would fill the voids satisfactorily, but this assumption is based only on probabilities projected from work under other conditions.

Other Foundation Treatment

In Tennessee Valley limestone rock, there are numerous places where grouting as such is not feasible, and where much more expensive open excavation or special shaft work is required to effect a cutoff wall against leakage. Prime examples of such work are at Chickamauga, Fort Loudoun, Guntersville, Kentucky and Hales Bar Dams.

At each of these projects the leakage or prospective leakage was stopped by mechanical cutoffs. At Chickamauga Dam, Tenn., open trench work was used down through all the bad rock into good rock, below which cement grout was placed. Fort Loudoun Dam, Tenn., and Guntersville Dam, Ala., offer excellent examples of gigantic dental jobs, where cavities were followed and cleaned out, then concreted and sealed by cement grout. At Kentucky Dam, Ky., a concrete arch was built by drilling 48-in. core drill holes in steps, tunnelling out and concreting; then redrilling and advancing another step downward. By alternating blocks, a concrete arch 100 ft. long and 200 ft. deep was eventually built, practically all below the normal level of the rock, which was rotten throughout. At Hales Bar Dam, to meet a different problem, 18-in. overlapping core drill holes, lined and concreted, were used for this cutoff to a depth of 100 ft. in

rock and up to 160 ft. from the base of operations.

Conclusion

It should be emphasized that cement, asphalt, chemical or any other type of grouting is never the panacea for all foundation evils. Each problem requires careful and experienced analysis, after which a specially prepared solution should be developed to meet the particular requirements at that location. Thus, and thus only, will the right solution to highly specialized problems be derived. These problems are expensive, and owners who have them must be prepared either to recognize this and bear the expense or be troubled with continual annoyance and the added expense of half measures. Certain principles of practice have stood out as superior to others, yet invariably modifications in these manifest themselves, and bear investigation. There is always something to learn.

Chemical Warfare and Water Supplies

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A Contribution to the Journal

TWO requirements for water which is to be supplied to troops in the field are recognized as indispensable: that it be free of pathogenic organisms and that it contain no harmful concentrations of toxic substances. In addition, of course, the water is expected to be as palatable and attractive in appearance as the tactical situation and the available water treatment facilities will permit.

In time of war, the greatest danger of water contamination by toxic substances is presented by the constant threat of an attack with chemical warfare agents, to which danger surface supplies are particularly vulnerable. Toxic, irritant or obnoxious contaminants may also be placed intentionally in pipelines, cisterns, wells, storage tanks and small bodies of water by retreating armies or saboteurs.

As war clouds gathered over Europe, considerable interest was aroused in the study of water contamination problems which could result from chemical warfare or sabotage. Most of the early work done in this country on problems of water contamination with chemical contaminants was conducted at Edgewood Arsenal, Md., under the auspices of the Chemical Warfare Service. Later, the studies continued under Army Medical Dept. supervision.

In the latter part of 1941, real impetus was given to the study of chemical warfare agents in water by the initiation of an extensive research program at the Chemistry Laboratories of the Univ. of Illinois. This program was carried out under a contract, recommended by the National Defense Research Com., between the Office of Scientific Research and Development and the university. Also upon recommendation of the NDRC, similar projects were initiated in the early part of 1943 at the Case School of Applied Science, Cleveland, Ohio, and at Louisiana State Univ., Baton Rouge, La. The work conducted by the civilian research groups then took the form of co-operative investigations in close collaboration with personnel of the Water Supply and Equipment Branch, The Engineer Board, Fort Belvoir, Va., and the Water Chemistry Section of the Medical Div., Chemical Warfare Service, Edgewood Arsenal, Md.

Much information has been compiled as a result of the studies and experimental investigations carried out by civilian and military organizations, and much credit is due to all those who participated in the research programs. Their contributions made possible a more logical appraisal of the problems created by the presence of deleterious

substances in water. Their work was of particular value in the design of water testing equipment and in the formulation of policies on selection and treatment of water sources in areas exposed to contamination by chemical warfare agents.

In accordance with present War Dept. policy, much of the research material accumulated during the past years is to be released and will appear in the literature of the field from time to time. For the most part, these publications will be of a highly technical nature and will be limited to discussion of isolated topics.

The broad outlines of the subject of chemical warfare and its possible effects on water supplies, however, may be presented and discussed here together with some of the problems which could arise from the intentional or accidental contamination of water sources with chemical substances. Particular reference is made to Army practice in handling these problems in the field.

Chemical Contaminants

The chemical substances that may cause water contamination are those which have toxic properties (casualty-producing substances) and those capable of imparting irritating or obnoxious tastes or odors (water denial agents).

These contaminants may be organic or inorganic substances. The organic substances include most of the chemical warfare agents, poisonous compounds of the alkaloid and glucoside groups and taste- and odor-producing substances, such as fish oil and bone oil. The inorganic substances include the soluble arsenic, cyanide and selenium salts and some of the compounds of lead, mercury and thallium.

Of these chemical substances, the chemical warfare agents, because of their ready availability for tactical use and because of the highly effective methods developed for their dispersal by means of air and ground weapons, present the greatest threat of broad-scale contamination of water sources.

Extensive contamination of water supplies with toxic concentrations of alkaloids, glucosides and inorganic poisons is a possibility. The large amounts of these substances required to produce lethal concentrations in sizable bodies of water, however, would make the undertaking decidedly difficult. Much more feasible would be the contamination of water with taste- and odor-producing agents. Nevertheless, it is doubtful whether any of these substances will be used for other than the intentional contamination of relatively small volumes of water in pipelines, wells and storage tanks.

Chemical Warfare Agents in Water

The chemical warfare agents have been defined as substances useful in war, which, by their ordinary and direct chemical action, produce a toxic effect, a screening smoke or an incendiary action. By toxic effect is meant any deleterious physiological action they cause when applied to the body externally, breathed or taken orally in moderate doses.

Although substances capable of producing toxic effects are of greatest interest in the contamination of water supplies, the compounds used in incendiaries (Table 1) and in screening smokes (Table 2) may also play an important role in water contamination by rendering the water nonpotable because of the tastes, odors, turbidity or color which they may impart.

Well over a thousand toxic chemical compounds have been studied in order to determine their suitability for use in

TABLE 1

Effects of Incendiaries on Water Supplies

Agent		Crude Oil	Magnesium	Thermit	White Phosphorus
Solubility in Water		Insoluble	Insoluble	Insoluble	Insoluble, but soluble as oxide
Physical Characteristics of Water	Turbidity	Present	Present	Present	Present
	Color	Brownish	None	Present	None
	Taste, Odor	Oily	Acid	Acid	Very acid
Physiological Characteristics of Water		Production of toxic water very unlikely (presence of insoluble elemental phosphorus a possible exception). All non-potable due to physical characteristics.			

TABLE 2

Effects of Screening Smokes on Water Supplies

Agent		FS Mixture	Titanium Tetrachloride	HC Mixture	White Phosphorus
Solubility in Water		Very soluble	Insoluble. Forms the hydroxide.	Some constituents are soluble	Insoluble, but soluble as oxide
Physical Characteristics of Water	Turbidity	None	Present	Present	Present
	Color	None	None	Slight, black	None
	Taste, Odor	Very acid	Acid	Slight, metallic	Very acid
Physiological Characteristics of Water		Production of toxic water very unlikely (presence of insoluble elemental phosphorus a possible exception). All non-potable due to physical characteristics.			

chemical warfare. Of these, less than twenty have been found to be capable of dispersion in sufficiently toxic concentrations in the field, and to meet other requirements (such as stability in storage, availability of raw materials, possibility of large-scale manufacture and suitability for loading in munitions) which are considered essential in usable chemical warfare agents.

Although these usable agents are capable of producing casualties on inhalation or contact with the skin, their value as water contaminants depends also on their oral toxicity, their solubility in water, the rate at which they hydrolyze, their tendency to react with other substances present in water and the toxicity of the newly formed products. For this reason, the physiological characteristics of water contaminated with substances such as the relatively insoluble arsenic-containing vomiting gases (Table 3) and the highly toxic but easily hydrolyzed chok-

TABLE 3

Effects of Vomiting Gases on Water Supplies

Agent		Diphenylamine-chlorarsine	Diphenylchlorarsine	Diphenylcyanarsine
Solubility in Water		Satd. soln. contains approx. 60 ppm.	Sat. soln. contains approx. 50 ppm.	Satd. soln. contains approx. 15 ppm.
Physical Characteristics of Water	Turbidity	Present	Present	Present
	Color	Slight brown	None	None
	Taste, Odor	None	None	None
Physiological Characteristics of Water.		Saturated solution non-toxic if no large excess of agent present in suspension.		

TABLE 4

Effects of Tear Gases and Choking Gases on Water Supplies

Agent		Chloraceto-phenone *	Chlorine	Phosgene †	Chlorpicrin
Solubility in Water		Slightly soluble. 600 ppm.	10,000 ppm.	Hydrolyzes	About 1,700 ppm.
Physical Characteristics of Water	Turbidity	Present	None	None	None
	Color	None	None	None	None
	Taste, Odor	Lachrymatory, biting, peppery	Strongly pungent	May be acid in low alkalinity water	Lachrymatory, biting, peppery
Physiological Characteristics of Water.		Satd. soln. non-toxic but non-potable due to very biting and peppery taste.	Undrinkable at toxic concentrations.	Non-toxic but may be non-potable due to acid produced on hydrolysis.	Satd. soln. non-toxic but non-potable due to very biting and peppery taste.

* Tear gas. Other agents in table are choking gases.
† Data for diphosgene similar to that for phosgene.

ing gas phosgene (Table 4) are not what would be expected from their physiological effects when inhaled.

On the other hand, the blister gases (Table 5) may remain undissolved in water, retaining their toxic and vesicant properties, or they may hydrolyze slowly into other toxic compounds. Water contaminated with the blood and nerve poisons (Table 6) may likewise remain toxic for some time, due to their very slight tendency to hydrolyze

TABLE 5

Effects of Blister Gases on Water Supplies

Agent		Mustard	Nitrogen Mustards *	Lewisite	Methyldichlorarsine	Ethyldichlorarsine
Solubility in Water		About 700 ppm. with hydrolysis	100 ppm. with hydrolysis	10,000 ppm. with hydrolysis	20,000 ppm. with hydrolysis	Above 1,000 ppm. with hydrolysis
Physical Characteristics of Water	Turbidity	Present	None	None	None	None
	Color	Pale yellow	None	None	None	None
	Taste, Odor	Obnoxious	Slight fishy	Obnoxious	Pungent	Pungent
Physiological Characteristics of Water		Toxic only if unhydrolyzed mustard present; otherwise non-potable due to taste and odor.	Very likely to be toxic in low pH water or water deficient in alkalinity	Very likely to be toxic because of high solubility and arsenic content.		

* Data applies primarily to compound $(ClC_2H_4)_2N$.

in natural waters. The blister gases and the blood and nerve poisons are, therefore, the most important of the potential chemical contaminants of water supplies.

Blister Gases in Water

The better known blister gases are sulfur mustard, lewisite and the nitrogen mustards. These so-called "gases" are oily liquids at ordinary temperatures and pressures. The plant-run products are usually dark brown in color; their specific gravity varies from 1.3 to 1.9. When introduced into a body of water, these substances tend both to form surface films and to fall to the bottom as globules. For this reason, the least contaminated water will usually be found in the zone between the surface film and the bottom deposits in reservoirs or slowly moving streams. Since solution takes place only at the agent-water interface, the rate of solution of these agents is slow, and bottom deposits of active material could easily remain in calm water for extended periods of time, perhaps months.

The surface films and oily droplets of the blister gases retain their toxic and vesicant properties and are capable of producing typical lesions on the skin of persons who use the contaminated water for swimming or bathing, and on the mouths and digestive tracts of those who drink it. A number of casualties among troops was recorded as a result of bathing in a stream which had accidentally been contaminated with a small quantity of sulfur mustard several days previously.

As soon as blister gases go into solution, however, there is a tendency for them to react with water (hydrolyze) at a more or less rapid rate to form hydrochloric acid and other compounds which in some instances are less toxic than the original substances. The hydrolysis of sulfur mustard, lewisite and one of the nitrogen mustards is indicated in the following equations:

As indicated in these equations, hydrochloric acid is one of the reaction products in the hydrolysis of blister gases. Therefore, in waters with insufficient alkalinity to neutralize the acid produced, hydrolysis cannot proceed to completion; and some of the toxic and vesicant compounds may remain unchanged in solution.

At ordinary temperatures, the hy-

$$(ClC_2H_4)_2S + 2H_2O \xrightarrow{\text{(rapid)}} (HOC_2H_4)_2S + 2HCl$$

Sulfur Mustard + $2H_2O$ → Thiodiglycol + 2HCl
(Toxic and vesicant) (Non-toxic and non-vesicant)

$$ClHC{:}CHAsCl_2 + H_2O \xrightarrow{\text{(instantaneous)}} ClHC{:}CHAsO + 2HCl$$

Lewisite + H_2O → Lewisite Oxide + 2HCl
(Toxic and vesicant) (Toxic and vesicant)

Other "arsenical" blister gases, such as methyldichlorarsine and ethyldichlorarsine, are also rapidly hydrolyzed to their corresponding oxides in the manner indicated for lewisite:

drolysis of sulfur mustard to harmless thiodiglycol is rapid, about 100 ppm being completely hydrolyzed (for all practical purposes) in about one hour. It is well to remember, however, that

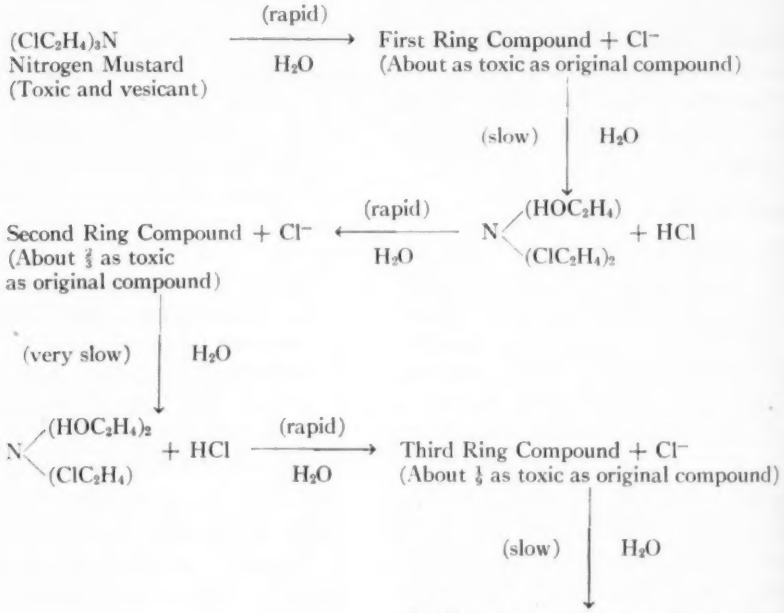

FIG. 1. "Screening Kit" for the Detection of Chemical Warfare Agents

he agent must go into solution before it can hydrolyze, and that the solubility ate of sulfur mustard in quiet water s very slow. Although water contain- ng completely hydrolyzed sulfur mus- ard is non-toxic and non-vesicant, it nay, nevertheless, be non-potable be- cause of its objectionable odor and taste.

Lewisite and the other arsenical blister gases hydrolyze instantaneously to form their respective oxides, which are toxic and vesicant. Here again, the slow solubility rate of the agent

TABLE 6

Effects of Blood and Nerve Poisons on Water Supplies

Agent		Cyanogen Chloride	Hydrocyanic Acid
Solubility in Water		60,000 ppm.	Soluble in all proportions
Physical Characteristics of Water.	Turbidity	None	None
	Color	None	None
	Taste, Odor	Sharp, biting, lachrymatory	Sharp odor. Bitter taste
Physiological Characteristics of Water.		Toxic and non-potable due to taste and odor.	Toxic and non-potable due to taste and odor.

may permit the accumulation of unhydrolyzed material in calm water.

The hydrolysis of the nitrogen mustards is a complex reaction. It proceeds in several steps and may stop short of completion in waters with insufficient alkalinity to neutralize the acid formed on hydrolysis. The intermediate hydrolysis products are toxic in varying degrees, but the final product of hydrolysis is non-toxic and non-vesicant. The complete hydrolysis of 100 ppm. of $(ClC_2H_4)_3N$ dissolved in water containing over 100 ppm. of alkalinity (expressed as $CaCO_3$) requires from one to two days at ordinary temperatures.

Blood and Nerve Poisons in Water

Cyanogen chloride (CNCl) is considered an effective chemical warfare agent since it not only has an extremely sharp and irritating odor but is intensely lachrymatory and highly toxic as well. Because of its low boiling point, 12.5°C., it is a gas at ordinary temperatures and, therefore, is classified as a non-persistent agent.

In spite of its high volatility and non-persistent nature, cyanogen chloride dissolves readily and extensively in water under field conditions to give aqueous solutions which may retain considerable quantities of the agent even after several days standing. Water containing 50 ppm. of cyanogen chloride would be refused in most cases because of its irritating effect on the throat. At 75 ppm. or over, the contaminated water is undrinkable. For this reason, it is doubtful if individuals could ingest toxic doses of cyanogen chloride in drinking water. Nevertheless, its effectiveness as a water denial agent alone would suffice to make this compound an important water contaminant.

In water, cyanogen chloride is very slowly hydrolyzed to cyanic acid as indicated by the equation:

$$CNCl + H_2O \longrightarrow HCNO + HCl$$

This reaction proceeds much faster in the presence of hydroxyl ions to form the relatively harmless cyanates. The ultimate hydrolysis of the cyanic acid to ammonia and carbon dioxide according to the equation:

$$HCNO + H_2O \longrightarrow NH_3 + CO_2$$

proceeds very slowly at ordinary pH values.

Hydrocyanic acid (HCN) is a colorless, highly volatile liquid which boils at 26°C. Its vapor is non-persistent and has the odor of bitter almonds. This acid is miscible in all proportions with water and, as with cyanogen chloride, its vapor has been found to dissolve readily in water under field conditions. In alkaline water, hydrocyanic acid forms cyanide salts which are soluble and stable. The toxicity of these salts is equal to that of equivalent concentrations of the acid.

Upon chlorination, as practiced for the disinfection of military water supplies in the field, the cyanide is converted into cyanogen chloride, thus creating a water-denial problem.

Detection of Contamination in Water

A critical inspection of a water source and surrounding territory may sometimes reveal the presence of undesirable chemical contaminants. The appearance, taste and odor of the water, the wilting and discoloration of nearby vegetation, the presence of dead aquatic animals and similar evidence are all significant indications which should arouse suspicion. Warning

the possible presence of undesirable chemical compounds in water may also be given by the results of certain routine water treatment control tests such as abnormally low or high pH and inability to obtain chlorine residuals with the usual chlorine doses.

Useful as these observations are, it is obvious that they may be misleading at times. For this reason, the need of confirming the presence of harmful contaminants by chemical tests becomes apparent.

Mainly through the efforts of the NDRC research group at the Univ. of Illinois Chemical Laboratories and the personnel at the Water Chemistry Section of the Medical Div., Chemical Warfare Service, Edgewood Arsenal, Md., two water-testing kits were developed and standardized as Army Medical Dept. items for the detection of chemical contaminants. One of these, commonly known as the "screening kit," is a pocket-sized outfit intended primarily for the testing of natural water sources. The other, referred to as the "suitcase kit," is a more elaborate portable laboratory suitable for water treatment control work and for determining the potability of treated waters.

Use of "Screening Kit"

The "screening kit" was designed for reconnaissance purposes in areas known or suspected to have been under attack with chemical warfare agents. When properly used, this kit will either give the "go-ahead" sign on the supply or will indicate a water so contaminated with chemical agents that it cannot be rendered potable by ordinary field water treatment procedures.

For the sake of simplicity in operation, analytical procedures have been developed to employ dry reagents only. These are furnished as tablets or pellets of proper size for the performance of each test. Except for warming with the hand in some of these tests, no heat is required. The reagents and equipment are packed in a container 5½ by 1⅞ by 3¼ in. When fully loaded for testing 15 samples of water, the kit weighs about 1 lb. Figure 1 shows the "screening kit" in use.

Simple instructions for performing the tests and interpreting results are contained in a booklet which is fitted in the cover of each kit. The chemical processes involved in the tests and the results obtained may be briefly outlined:

(a) *Arsenic Test (Modified Gutzeit):* Arsenicals are converted to arsines through the action of nascent hydrogen produced by the reaction between acid, added in the form of sodium acid sulfate, and metallic zinc. The arsine reacts with an indicator paper strip, sensitized with mercuric chloride, to produce a stain. A positive test is indicated by a stain ¼ in. or more in length; such a stain is produced by a 20 ppm. concentration of lewisite.

(b) *pH Test:* The pH is determined by means of pH indicator paper and a pH color chart. A pH below 6 or above 9 is considered a probable indication of chemical contamination.

(c) *Mustard Test:* Mustards and the toxic hydrolysis products of the nitrogen mustards are detected by means of a special reagent known as "DB–3." The sensitivity of the test is on the order of 4 ppm. of nitrogen mustard, and about 50 ppm. of "third ring compound." The appearance of any reddish or blue color in the solution is a positive test for active mustard.

TABLE 7

Interpretation of Results Obtained With the "Screening Kit"

Field Test	*Results*	*Compounds Absent in Objectionable Concentrations*
Chlorine Demand	Negative	Sulfur mustard, lewisite, methyldichlorarsine, ethyldichlor arsine, diphenylcyanarsine, cyanides, trivalent arsenic a arsenite
Mustard	Negative	Sulfur mustard, "nitrogen mustards," cyanogen chloride
Arsenic	Negative	Lewisite, methyldichlorarsine, ethyldichlorarsine, phenyl dichlorarsine, inorganic arsenicals
pH	6 to 9*	Phosgene, diphosgene, intermediate hydrolysis products o "nitrogen mustards"
Taste and Odor†	None	Cyanogen chloride, hydrocyanic acid, chloroacetophenon chlorpicrin, sulfur mustard
Turbidity and Color‡	None	Adamsite, diphenylchlorarsine

* With low alkalinity waters.

† Taste and odor refer particularly to those directly attributable to the presence of tox compounds.

‡ Turbidity and color are to be interpreted in light of local conditions and usually wi mean "None in excess of those normally existing after purification by ordinary methods o water treatment."

Cyanogen chloride, in concentrations over 5 ppm., produces a yellow color with the "DB–3" reagent.

(d) *Chlorine Demand Test:* The chlorine demand is determined by means of halazone tablets and an orthotolidine residual chlorine testing assembly. This test indicates the presence of a number of agents which may or may not give positive tests for "mustards" or "arsenicals" and includes cyanide when present in concentrations greater than 3 ppm. A positive test is indicated by failure to obtain 1 ppm. or more of residual chlorine after a 5-minute contact period when using a 6-ppm. chlorine dose.

(e) *Taste and Odor:* Absence of all tastes and odors will not necessarily indicate a safe water since some of the toxic agents do not impart a noticeable taste or odor. On the other hand, the presence of only those odors or tastes normally characteristic of natural waters is considered to be a negative test. A lachrymatory or pungent odor, biting or peppery or chlorinous tast and any taste or odor of a known chem ical warfare agent are considered posi tive tests.

If any one of the "screening kit" tests gives a positive result, the wate source is not to be used without fur ther investigation.

From the criteria used in establish ing what constitutes a "positive result" for the above determinations, it is ob vious that negative results by th "screening kit" procedures do not nec essarily mean complete absence o chemical contaminants. The basis se lected to determine acceptability o water sources, therefore, takes int account the possible need of using, un der critical circumstances, water whic contains chemical contaminants, pro vided that their concentrations do no produce toxic or harassing effects whe the water is consumed in normal vo umes. This criterion, however, is in

FIG. 2. Use of "Suitcase Kit" in the Field

tended to apply only to waters which are to be treated by standard field procedures, such as coagulation, filtration or chlorination, and that are to be used sparingly for relatively short periods of time, not exceeding one week. The time limit is intended to guard against possible cumulative effects. A scheme for the interpretation of results obtained with the "screening kit" is given in Table 7.

Use of "Suitcase Kit"

Where the results of the "screening kit" tests question the safety of the water, or where it is found necessary to treat water for the removal of chemical warfare agents, the "kit, water testing, poisons, treatment control ('suitcase kit')" is to be used. This kit contains apparatus and chemicals needed for the quantitative determination of "mustards," "arsenicals," pH and chlorine demand. The "suitcase kit" also contains equipment and reagents for the qualitative determination of cyanogen chloride, cyanide, lead, thallium, mercury and selenium. With the data obtained by means of these determinations, it is possible to ascertain the type and extent of treatment needed in order to estimate the feasibility of treating the water. These same quantitative tests must be used to determine the potability of the treated water.

The carrying case of the treatment-control kit resembles in size and shape an ordinary suitcase. Its approximate dimensions are 26 by 16 by 10 in. This kit (Fig. 2), fully loaded for use in the field, weighs about 60 lb. and contains enough reagents for testing 25 samples of water. The equipment and reagents are packed in such a manner that the kit is capable of withstanding rough field handling without breakage. Reagents which are relatively unstable in solution are packed dry in weighed amounts, ready to be dissolved in the appropriate solvents provided in the kit when the equipment is first used in the field.

A manual of instructions, giving specific directions for the preparation of solutions and the performance of tests, is issued with the kit. Briefly, the tests involve the following chemical processes:

(1) (a) Mustards are determined by the "DB–3" test. This test is a quantitative application of the same reaction involved in the qualitative mustard test in the "screening kit." The use of liquid reagents, the more careful control of pH and temperature, and the use of acetone for stabilization of the color produced, make possible the quantitative estimation of mustards by the "DB–3" procedure. The mustard concentration is determined by comparing the color developed in the test solution with that of permanent color standards on a special war gas disk in a color comparator.

(b) A yellow color appearing after the addition of "DB–3" reagent indicates the presence of cyanogen chloride.

(2) Arsenic is determined by the standard molybdenum blue procedure. Ammonium persulfate and heat are used to break the carbon-arsenic bond and to oxidize the arsenic to the pentavalent form. The pentavalent arsenic is then made to react with molybdate to form a complex ion which, when reduced by hydrazine sulfate, gives the solution a blue color. The intensity of this color is proportional to the amount of arsenic present. The arsenic concentration can then be determined by comparing the color of the solution with that of the arsenic color standards of the war gas disk in the color comparator.

(3) The quantitative chlorine demand is determined by adding a known volume of standard "Chloramine-T" * solution to a given volume of water, previously acidified to pH 1, and determining the free chlorine remaining after a 5-minute contact period by iodometric titration. "Chloramine-T" was selected as the chlorinating agent because of its stability. The oxidation potential of "Chloramine-T" varies with pH, the highest potential being attained at pH 1. Sulfamic acid is used to prevent nitrites from interfering with the test.

(4) The quantitative pH determination is made by means of the color comparator using a wide-range pH indicator and a wide-range pH color disk.

(5) Cyanide, when present in concentrations greater than 5 ppm., gives a reddish brown color in an alkaline picrate solution. Picric acid and sodium carbonate solutions are the reagents used. Heating in a boiling water bath is necessary for color production.

* "Chloramine-T" is a commercial product developed by the Monsanto Chemical Corp. and distributed through the Abbott Chemical Co., Inc.; Heyden Chemical Corp.; Merck & Co., Inc.; and E. R. Squibb & Sons. The product is usually sold in tablet form, one tablet (4.6 grains) in an ounce of water yielding a 1 per cent solution.

(6) In ammoniacal solution containing potassium cyanide and ammonium citrate, dithizone gives colored precipitates with lead and thallium. These precipitates are readily soluble in organic solvents such as chloroform. If a sample of water containing lead or thallium is treated with L.T. reagent (lead-thallium reagent—an ammoniacal solution containing cyanide and citrate ions to prevent interference from other heavy metals) and then treated with a chloroform solution of dithizone, the green color of the reagent will turn pink or reddish in the presence of 1 ppm. or more of lead or thallium.

(7) When a solution is acidified with nitric acid and treated with a chloroform solution of dithizone, the green color of the reagent turns to an orange-yellow in the presence of 1 ppm. or more of mercury.

(8) Selenium is detected by acidifying a sample of water with hydrochloric acid and adding hydrazine sulfate to the solution. The formation of a red color or preciptate, after heating for 5 minutes in a boiling water bath, indicates the presence of 5 ppm. or more of selenium.

The criterion used for appraising the potability of treated waters, on the basis of results obtained by the "suitcase kit" procedures, is that the water must be considered unsafe if it contains more than 2 ppm. of "active mustards" or an arsenic concentration greater than 7 ppm. (expressed as As), or if its chlorine demand is in excess of 5 ppm. or its pH is less than 5. In addition, of course, the water must have no chemical odor or taste. Water giving positive results with any of the qualitative procedures for cyanide, selenium, lead, thallium and mercury is also considered unsafe.

The relatively high concentrations of chemical contaminants tolerated by this criterion again presuppose only the moderate use of the treated water for limited periods of time, not to exceed one week.

Water Treatment

The object of treating water which contains chemical contaminants is to make it non-toxic, potable and palatable. This may be accomplished by removing the contaminants or by converting them into less objectionable substances through chemical reactions. Whenever possible, removal of contaminants is to be preferred, since the products of chemical reactions may impart sufficient taste or odor to affect the potability of the water.

The treatment of water for the removal of chemical contaminants is a slow and laborious process which requires close technical supervision and, in most instances, the use of large quantities of chemicals for treatment. For this reason, it has been emphasized time and again that every effort must be made to find an uncontaminated source for military water supplies in the field before attempting the treatment of water known to contain toxic substances. Since contaminated sources of water may have to be used at times, however, a number of procedures have been studied in an effort to determine their applicability and limitations in the treatment of waters containing objectionable chemical contaminants.

Hydrolysis

Hydrolysis plays an important role in the decomposition of some of the toxic chemical warfare agents in water and may even be thought of as a natural water purification process for

contamination by chemical substances. This is true of compounds such as the toxic phosgene and diphosgene, which react with water very rapidly to form hydrochloric acid and carbon dioxide, which can usually be neutralized completely by the alkalinity in natural waters. On the other hand, the arsenical blister gases, such as lewisite, methyldichlorarsine and ethyldichlorarsine, hydrolyze to their corresponding oxides, which are toxic and vesicant.

As already mentioned, sulfur mustard and the nitrogen mustards are rendered non-toxic by reaction with water, provided that sufficient time is allowed and there is enough alkalinity in the water to neutralize the acid formed on hydrolysis to allow the reaction to proceed to completion. The effectiveness of hydrolysis as a purification procedure for water contaminated with "mustards," however, is seriously affected by the slow solubility rate of these substances in quiet water.

Hydrolysis rates can sometimes be accelerated by means of chemical treatment. For example, the reaction of cyanogen chloride with water to produce the relatively harmless cyanate can be made to proceed much faster by proper treatment of the water with soda ash or lime. It takes about 4 ppm. of Na_2CO_3 for 1 ppm. of CNCl in low alkalinity waters, and, if the cyanogen chloride concentration exceeds 100 ppm., the treated water is not palatable. Other compounds, such as hydrocyanic acid, cannot be hydrolyzed readily.

Activated Carbon

Some of the better water-treatmen powdered activated carbons have bee found highly satisfactory for the re moval of odors, tastes, unhydrolyze nitrogen mustards, lewisite and re lated arsenicals, sulfur mustard an thiodiglycol. To a lesser extent, the are also capable of removing partl hydrolyzed nitrogen mustards. Fo this reason, these activated carbon have been accepted as the essentia materials for treatment of water con taminated with chemical warfare agents The doses required are about 20 ppm of carbon for 1 ppm. of lewisite, sulfu mustard or thiodiglycol, and 60 ppm for 1 ppm. of partly hydrolyzed nitro gen mustards.

The usual contact period given fo adsorption of the contaminants b powdered carbon is about 30 minutes The suspension of contaminated car bon is then removed by coagulation sedimentation and filtration. Ammo nium alum is used as the coagulant, th doses required being from 120 to 17 ppm. When required, enough soda ash is used to produce a satisfactor alum floc.

Activated carbon is not effective fo the removal of the blood and nerv poisons, hydrocyanic acid and cyanoge chloride.

Chlorination

Chlorination of military water su plies is always required. When wate containing blister gases is chlorinate however, the following reactions occu

$$(ClC_2H_4)_2S + Cl_2 + H_2O \longrightarrow (ClC_2H_4)_2SO + 2HCl$$

Sulfur Mustard + Cl_2 + H_2O (Toxic and vesicant) → Sulfoxide of Mustard + 2HCl (Toxic)

$$(ClC_2H_4)_2SO + Cl_2 + H_2O \longrightarrow (ClC_2H_4)_2SO_2 + 2HCl$$

Sulfoxide of Mustard + Cl_2 + H_2O (Toxic) → Sulfone of Mustard + 2HCl (Toxic and stable)

It is apparent, then, that the chlorination of water containing unhydrolyzed sulfur mustard produces toxic and stable compounds.

The non-toxic thiodiglycol (which is the product of hydrolysis of sulfur mustard) forms the harmless thiodiglycol sulfoxide and sulfone very much in the manner that the corresponding compounds of sulfur mustard are formed. Thus, there is no harm in chlorinating water containing *only* thiodiglycol. Since unhydrolyzed mustard may also be present in water containing thiodiglycol, however, the procedure is dangerous. Besides, this reaction consumes about 1 ppm. of chlorine for a like amount of thiodiglycol; and, since the chlorine uptake of thiodiglycol is slow, a false sense of security may be gained from apparently adequate chlorine residuals.

Lewisite is present in solution as lewisite oxide. This compound reacts rapidly and quantitatively with chlorine to form chlorovinylarsonic acid, a substance much less toxic than lewisite oxide, as shown in the following equation:

$$\underset{\substack{\text{Lewisite Oxide} + Cl_2 + 2H_2O \\ \text{(Toxic and vesicant)}}}{ClHC{:}CHAsO + Cl_2 + 2H_2O} \xrightarrow{\text{(Rapid)}} \underset{\substack{\text{Chlorovinylarsonic Acid} + 2HCl \\ \text{(Much less toxic than lewisite oxide)}}}{ClHC{:}CHAsO_3H_2 + 2HCl}$$

Methyl, ethyl and phenyldichloroarsine are similarly oxidized to the corresponding acids by treatment with chlorine.

Although lewisite and its oxide are very readily removed from solution by activated carbon, the chlorovinylarsonic acid, formed by chlorination, is very difficult to remove by carbon treatment. The chlorine uptake of lewisite is about 0.3 ppm. of chlorine for 1 ppm. of lewisite.

The extent of reaction of the nitrogen mustards with chlorine is negligible in the concentrations in which this disinfectant is used for the treatment of field water supplies.

From the preceding discussion, it must be concluded that when blister gases are present in water, they must be removed by carbon treatment before the water is chlorinated.

At pH values between 7 and 8, cyanogen chloride reacts with hypochlorite as follows:

$$\underset{2(\text{Cyanogen Chloride}) + 3HOCl + H_2O}{2CNCl + 3HOCl + H_2O} \longrightarrow \underset{5HCl + 2CO_2 + N_2}{5HCl + 2CO_2 + N_2}$$

The chlorination products of cyanogen chloride are thus seen to be harmless substances. This reaction, however, is somewhat slow. One ppm. of cyanogen chloride takes up 1.8 ppm. of chlorine.

Chlorine reacts rapidly with hydrocyanic acid to form cyanogen chloride. It takes 2.7 ppm. chlorine to react with 1 ppm. of hydrocyanic acid. As indicated above, the cyanogen chloride formed by chlorination of the acid can be made to react with more chlorine to form harmless hydrolysis products.

In practice, chlorination alone was not found satisfactory for the treatment of water contaminated with hydrocyanic acid or cyanogen chloride because of the large amounts of chlorine required to treat water contaminated with harassing or toxic concentrations of these agents and the objectionable taste of the treated water.

Aeration

The high vapor pressures of hydrocyanic acid and cyanogen chloride at ordinary temperatures suggest the pos-

sibility of utilizing aeration as a practical field procedure to remove these two non-persistent agents from water.

Vigorous aeration, either by spraying water into the air or by blowing air into the water, is an effective method for the removal of cyanogen chloride and produces a safe water free from objectionable taste and odor. Aeration alone is not too effective for the removal of moderate concentrations of hydrocyanic acid from water. Since the acid is readily converted into cyanogen chloride by chlorination, however, a combination chlorine-aeration treatment can be used for its elimination from water. As stated above, 2.7 ppm. of chlorine is required to convert 1 ppm. of hydrocyanic acid to cyanogen chloride. A 60-minute period of vigorous aeration is effective in removing the cyanogen chloride formed by chlorination of hydrocyanic acid. The treated water is safe and palatable.

Distillation

Distillation by means of the standard Army continuous feed, thermocompression-type distillation units is effective in removing sulfur mustard, nitrogen mustard and lewisite from water. The distillates, however, are non-potable, due to their objectionable odors, and must, therefore, be treated with powdered activated carbon. The carbon doses required for the removal of these distillate odors are about $\frac{1}{5}$ of those required to remove the original concentration of "arsenical" blister gases and sulfur mustard in the raw water, and about $\frac{1}{15}$ of the amount of carbon required to remove the partly hydrolyzed nitrogen mustard by direct carbon treatment.

Continuous feed distillation is not effective for the removal of cyanogen chloride and hydrocyanic acid from water. From 70 to 85 per cent of the agent of cyanogen chloride contamination, however, is hydrolyzed in the still when the feed water is pre-treated with sufficient soda ash to raise its pH to a value between 9 and 10.

Boiling

Although boiling is an impractical treatment procedure when large volumes of water are involved, it may, nevertheless, be the only possible expedient for individuals or small groups under certain circumstances.

In alkaline waters, boiling accelerates the hydrolysis of the blister gases. This effect, however, is helpful only with the nitrogen mustards since, as previously mentioned, the other blister gases hydrolyze very rapidly at ordinary temperatures; and hydrolysis does not decrease the toxicity of the "arsenical" blister gases.

Vigorous boiling for 5 minutes in open containers is effective in removing cyanogen chloride (CNCl) from water. It is possible that the concentration of contamination with hydrocyanic acid (HCN), may be reduced to an acceptable level by boiling the water in open containers, provided that about one-fourth of the original volume of water is evaporated. This method, however, is not effective for the removal of alkali cyanides, nor for the removal of hydrocyanic acid in concentrations over 200 ppm. in high alkalinity waters.

Coagulation, Settling and Filtration

This procedure is effective for the removal of substances in suspension such as the products of combustion of incendiaries, screening smokes, vomiting gases and droplets of the blister gases. When alum is used as the coagulant, the procedure, by itself, is

TABLE 8

Relative Effectiveness of Procedures for Removal of Chemical Agents From Water

Treatment Procedure	Sulfur Mustard	Lewisite	Nitrogen Mustards		Phosgene and Diphosgene	Cyanogen Chloride	Hydrocyanic Acid	Incendiaries Screening Smokes Vomiting Gases
			Unhydrolyzed	Partly Hydrolyzed				
Hydrolysis								
Low Alkalinity Water	3*	4	3*	3*	2*	3*	4	4
High Alkalinity Water	2*	4	2*	2*	1*	2*	4	4
Activated Carbon (With Coagulation, Settling and Filtration)	1	1	1	3	4	4	4	1
Chlorination	4	3*	4	4	4	2*	3*	4
Aeration	4	4	4	4	1	1	2	4
Chlorination-Aeration	4	4	4	4	1	1	1	4
Continuous Distillation (With Carbon Treatment of Distillate)								
Low Alkalinity Water	1	1	1	1	2	3	4	1
High Alkalinity Water	1	1	1	1	1	2	3	1
Boiling								
Low Alkalinity Water	3*	4	2*	2*	1	1	2	4
High Alkalinity Water	2*	4	1*	1*	1*	1*	3*	4
Coagulation, Settling and Filtration	4	4	4	4	4	4	4	1

Legend: 1—Very good results; 2—Good results; 3—Fair results; 4—Poor results.

* Conversion to less toxic substances

ineffective for the treatment of water containing blister gases or blood and nerve poisons in solution. Under carefully controlled conditions, coagulation with ferric sulfate has proved satisfactory for the removal of arsenates from water. This procedure, however, is of little practical value because of the difficulty of liberating arsenic from the organic "arsenicals."

The relative effectiveness of the procedures discussed in the preceding paragraphs for the treatment of water contaminated with chemical warfare agents is shown in Table 8.

Newer Chemical Warfare Agents

In this presentation of water contamination problems, discussion has been limited to the better known of the chemical contaminants even though there are a few new chemical warfare agents, of the "blood and nerve poisons" type, which appear to have unusual possibilities. With the exception of a group of fluorine-containing com-

pounds, these newer members of the "blood and nerve poisons" group are readily detected and detoxified by the methods of analysis and treatment already described, or by simple modifications of these methods.

Special analytical procedures and an auxiliary water testing kit have been developed at the Water Chemistry Laboratories, Medical Div., Chemical Warfare Service, Edgewood Arsenal, Md., for the detection of fluoro-organic compounds in water. Reagents and equipment have been provided for two distinct procedures. One of these, referred to as the "spot test," is a rapid and simple procedure intended for screening. The other procedure, known as the "burner method," is to be used on waters for which the "spot test" is not applicable (alkalinity over 500 ppm. or fluoride content over 3 ppm.) and for occasional confirmatory checks. The essential steps in these procedures are the liberation of the fluorine from organic combination and the colorimetric detection of the released fluoride.

Summary

Adequate means for the detection of chemical contaminants, an understanding of the properties and behavior of these contaminants in water, and a knowledge of their oral toxicities, are essential in warfare. Proper appraisal must be made of the danger involved in the utilization of water sources contaminated with chemical substances, and there must be rational selection and control of methods of treatment when circumstances require the utilization of chemically contaminated waters.

Purchase and Maintenance of Deep-Well Pumps

By L. J. Alexander

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Presented on May 9, 1946, at the Annual Conference, St. Louis, Mo.

THE Southern California Water Co. has 107 turbine pumps in operation and purchases an average of 10 complete units each year. These pumps are located in 29 operating districts. Geographically, the districts are scattered from the vicinity of Sacramento to the Imperial Valley. They operate under climatic conditions ranging from the hot, dry desert to the snow-clad San Bernardino mountains. The wells in which the pumps operate are located at elevations varying from sea level to more than 7,000 ft.; the motors driving them vary in size from 7½ to 150 hp., and the capacity range is from about 100 to more than 2,200 gpm. In direct lift of water from the well, the variation is from just a few feet to more than 500 ft. below the surface.

The wide range of pumping conditions provides opportunities to shift pumps from one location to another, thereby practically eliminating the factor of obsolescence. A pump can always be installed in a well or system where it will operate to best advantage. With specifications standardized, it is possible to make these transfers even though there is considerable variation in character and quality of the water being pumped.

Wells and Water Quality

Wells drilled in Southern California are of two types: the California cable tool and the rotary gravel envelope. The cable tool method was developed in the early days of well drilling in Southern California because of the character of the geological formations into which wells must be drilled. These are all unconsolidated formations of the Recent, Pleistocene and Pliocene geologic epochs. The unconsolidation is such that open-hole drilling is impossible; the well casing must follow the drill. After the well is drilled, the casing, which is then in place, is perforated opposite water-bearing formations.

Rotary gravel envelope wells have pre-perforated casings set in the drilled and well-mudded hole. Gravel is then placed between the casing and the wall of the drilled hole.

The Southern California Water Co. has wells of both types, with depths ranging from less than 200 ft. to more than 1,900 ft. The unconsolidated formations in which these wells are drilled are so unstable that, regardless of the type of well, it is often impossible to keep out fine sand or silt. Even after very careful development of the well, it is occasionally necessary to resort to the use of a column check valve in the construction of a pump. In doing this a column check valve is installed immediately above the pump bowls to prevent water from draining out of the pump, with a consequent reversal of the flow from the well into the formation.

TABLE 1

Analysis of Water

	City Creek	Foothill	Garvey	Wadsworth	Golden West	Avalon	Colden	Pacific
Sodium	104.4	37.7	19.6	378.6	32.2	49.5	57.3	63.7
Calcium	1.2	32.1	37.6	10.0	57.5	69.6	106.8	105.2
Magnesium	Trace	6.7	11.2	2.5	10.3	13.4	21.8	42.7
Sulfate (SO_4)	84.5	7.2	18.2	3.8	44.1	91.2	197.3	179.0
Chlorine	19.0	12.0	20.0	198.0	29.1	33.0	53.5	82.0
HCO_3	109.3	201.3	164.7	699.0	207.3	231.7	244.0	335.5
Total Solids	319.0	321.8	284.5	1319.9	392.9	492.4	698.4	839.1
Carbonate Hardness	3.0	107.5	135.0	35.0	170.0	195.0	200.0	275.0
Other Hardness	—	—	5.0	—	16.5	34.0	156.5	162.0
Total Hardness	3.0	107.5	140.0	35.0	186.5	229.0	356.5	437.0

Sand within the water passages of the pump literally blasts away metal of bowls, impellers, shaft, casing and tubing. Experience has shown that bronze withstands this sand cutting better than any other metal. Porcelain-enameled cast-iron impellers have been tried, as porcelain is harder than sand and, thus, might be expected to withstand the abrasion; but sand cuts into the cast iron where the enamel has been machined off, and cavities develop between the porcelain and iron. It is only a matter of time until the porcelain spalls, due to corrosion of the iron.

Because many of these formations from which water is extracted were laid down under water, there are large areas where gases such as methane, carbon dioxide or hydrogen sulfide are entrained. These gases (or air from water falling from perforations above pumping water level) cause turbulence in the pump, and, in turn, excessive corrosion. Bronze and stainless steel withstand such corrosion better than iron or steel. In the pump column, at the top of the bowls, a short section of bronze tube will often withstand the corrosion caused by turbulence.

The well waters pumped represent a wide range in chemical characteristics. Hardness varies from just a few to more than 500 ppm.; the pH is between about 7.3 and 8.0. Total solids vary from less than 100 ppm. to a maximum of 1,500 ppm. In several wells, free carbon dioxide appears and, in a large number, free hydrogen sulfide. Some waters have no trace of either iron or manganese; others have as high as 2 ppm. iron and 1 ppm. manganese. Table 1 shows this wide range of chemical character in the water produced. It has not been possible to relate corrosion rates directly to the acid radicals contained in natural waters.

The most troublesome conditions under which pumps operate exist in those wells in which the waters have been highly contaminated with the iron and sulfur group of slime-forming organisms, and contain as much as 2 ppm. iron and 1 ppm. manganese and have a high concentration of free hydrogen sulfide. Such waters are devoid of dissolved oxygen, but the slime-forming organisms are anaerobic. Slime coatings of considerable thickness will form even on highly polished rotating parts, such as the impellers. As the slime increases in thickness, the water passage space is reduced in area; and

the efficiency of the unit reduced. Occasionally graphitic corrosion takes place to an alarming degree where these slime-forming organisms are present. Bronze parts are the least affected by the slime formers.

Corrosion

Corrosion of turbine pumps results from several causes: chemically corrosive waters, entrained gases, bacteria and differences in electric potential between parts of the unit. How each factor operates or affects the other is not known, but it is obvious that corrosion does occur and that preventive measures are necessary.

In extreme corrosion, whatever the cause, the best preventive measures are to use a stainless steel shaft, bronze bowls and impellers in the bowl assembly, a 5-ft. section of bronze oil tube, a stainless steel line shaft from bowls to static water level, with a coating of coal-tar enamel outside the oil tube and inside and outside the eduction pipe.

To check corrosive waters, the Wintroath Pump Co. has demonstrated that the better the grade of metal, the more resistant it is to corrosion. Many pump manufacturers, for their standard sales product, use an ordinary run of foundry gray iron. The Wintroath analysis shows a rather high electric potential between ordinary gray iron, bronze and stainless steel, which seems to be additional proof of what practice has long demonstrated: that the finer the metallurgy, the better the completed product.

Speed of rotation is another factor. It seems that the higher the speed, the greater the rate of corrosion. The author has found no satisfactory explanation of this correlation, and cannot determine whether it is due to corrosion alone, or partly to the turbulence caused by high velocity.

No attempt has been made to weigh individual parts of the pump to determine the extent of corrosion or wear in terms of the percentage of metal lost. Such an analysis in turbine pumps has little practical value because corrosion and wear never take place uniformly. A section of pump casing may lose less than 1 per cent by weight and still be unsafe because the casing is pitted. If pitting is allowed to continue, holes will cut through the casing and, under the high head of water in the pump column, act as nozzles. Wells have been damaged by such holes drilled through the well casing, and the loss of water through holes causes appreciable loss in pump efficiency. Corrosion and pitting at or near threads of the casing so weakens the pipe that failure can occur at a joint. When this occurs, the entire weight load of the pump and the hydrostatic thrust of water load are transmitted to the motor bearing and the rotating impellers. Such loads will wreck the entire unit.

In the pump bowls, a fraction of one per cent loss in weight, if in certain places, may be serious. On the other hand, if corrosion or sand cutting is uniform throughout, a 15 or 20 per cent loss in weight may not be serious.

Corrosion of the tubing may permit water under high head to enter the peripheral space between the tubing and the rotating pump shaft. Water will then shortly find its way out through the top of the tubing. When this occurs, the motor windings are often sprayed with water, resulting in a burned-out motor. Of less serious consequence, but equally troublesome, is the resulting corrosion of the line shafting. The company's specifications do not permit a packing gland at the

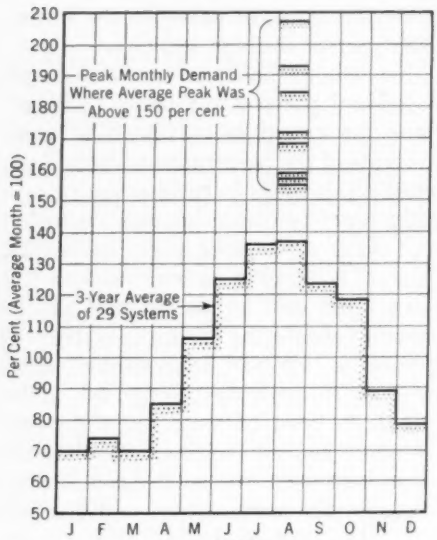
Peak Monthly Demand Where Average Peak Was Above 150 per cent
3-Year Average of 29 Systems
Per Cent (Average Month = 100)
Months
J F M A M J J A S O N D

FIG. 1. Average Monthly Production for All Systems

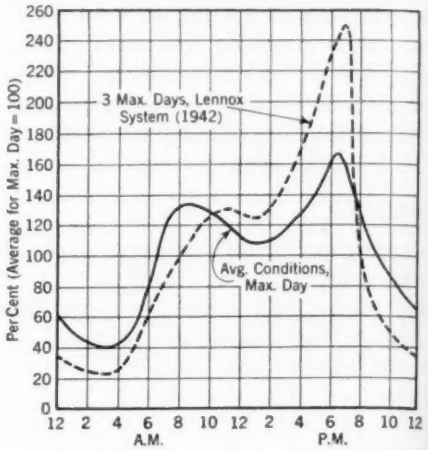

FIG. 2. Average Demand on a Maximum Day

top of the tubing, because a packing gland prevents the appearance of oil and water at the pump head. When even a very small hole appears in the tubing it can be detected quickly and immediately repaired.

Very slight wear in the motor bearings, even a fraction of one per cent, may change the position of the impellers in the bowls, and cause them to wear excessively. The efficiency of the unit is lowered almost immediately, even before serious wear occurs. Excessive wear in motor bearings also causes misalignment of bearing housings. Oil is thrown out of the housing and, in a very short time, saturates the motor windings so thoroughly that nothing short of rewinding the motor will save it.

No mathematical relationship or formula can be developed or deduced to replace experience and visual inspection in the choice and extent of repairs and replacements to parts of the pump, when it is pulled for overhaul.

Variation in Demand

The variation of consumer demand in arid countries is great. All living things require water regularly, but in Southern California nature provides water only in the winter rainy season. Irrigation is therefore necessary. Domestic water service must provide for irrigation of lawns, shrubs and flower gardens, as well as for industrial and household consumption.

Figure 1 shows the Southern California Water Co. monthly production compared to the average month (taken as 100 per cent). Together with the 3-year average for the 29 systems, the maximum months for several of the smaller systems are also shown. It appears that the smaller the system, the greater the peak demand. The average day of the maximum month averages nearly 140 per cent of the yearly average day; but the average day varies widely in the various systems. The average daily demand for 1945 is shown in Table 2. This table

TABLE 2

System Demands

System	County	No. of Customers * 3/13/46	Gals. per Customer * 1945	Max. Day, Per Cent of Avg. Day, 1945
Artesia	Los Angeles	547	423	199
Barstow†	San Bernardino	876	822	191
Bear Valley	San Bernardino	655	202	386
Bloomington	San Bernardino	376	394	193
Calipatria‡	Imperial	290	1621	—
Niland	Imperial	125	—	—
Bell	Los Angeles	2,549	460	174
Florence-Graham	Los Angeles	5,986	695	135
Cardena	Los Angeles	4,048	432	230
Lawndale	Los Angeles	2,747	378	201
Lennox	Los Angeles	4,569	370	172
Normandie	Los Angeles	1,650	324	198
So. Los Angeles	Los Angeles	7,905	359	208
Claremont	Los Angeles	1,185	707	311
Cypress	Orange	126	386	243
Highland	San Bernardino	603	388	188
Hollydale	Los Angeles	1,451	404	203
Huntington Beach	Orange	1,549	694	267
Oak Park	Sacramento	1,104	497	293
Ojai	Ventura	591	478	166
Olive	Orange	176	335	278
Placentia§	Orange	623	311	—
Atwood	Orange	—	—	—
Sunland-Tujunga	Los Angeles	3,359	432	201
Venice-Culver City	Los Angeles	14,978	515	139
Walnut Grove‖	Los Angeles	62	—	—
Wilmar	Los Angeles	3,062	325	190
Los Alamitos	Orange	215	527	172
Stanton	Orange	209	229	228

* An average of 4 consumers is served by each customer's service connection.
† Industrial use eliminated.
‡ Unmetered supply; consumption determined from several tests.
§ Part of supply unmetered.
‖ New system averages not established.

also shows the relationship of the maximum day to the average day.

There is an even greater variation in hourly demand. Figure 2 shows the average variation for each hour of the maximum day. The broken line represents the average of three consecutive maximum days in the Lennox system in 1942.

These curves all show the necessity for a large available capacity in primary pumping equipment. On the other hand, they show that, for large portions of the year, much of the equipment must remain idle. Experience has demonstrated that idle equipment deteriorates nearly as rapidly as operating equipment. The causes may be different, but replacements are just as costly. To overcome this problem partially, all equipment is operated at least once a week.

Weekly operation keeps the well in good order, dries out the motor wind-

ings, prevents "freezing" of bearings—particularly in the line shaft—tends to reduce the accumulation of slime growths and assures the operators that the equipment is in good order. This last is important because all equipment must "cut in" quickly and automatically in case of fire.

Planned Operation

Although all equipment is automatic, the time each unit operates can be predetermined. The general plan of operation to assure an adequate dependable primary supply is laid out in the engineering department. This plan is based on a study of the distribution pipe system and the location of the various pumping plants. Elevated storage is always considered as a balance against the maximum hour, and it is also desirable to consider it as a safety factor. Each plant is automatic, operation being controlled by pressures within the adjacent distribution system. Other factors entering into the setting of these controlling pressure ranges are: the quality of water produced at the plant, the efficiency of equipment, variations in demand, the needs of fire protection and the manpower available to operate the equipment.

The carrying out of these planned operations is under the direction of the construction engineer, who has charge of all field work on new construction, as well as maintenance, repair, replacement and operation. The district superintendents, of course, are "on the ground" and carry out most of the details of the operation of pumping plants.

Checks on Operation

To check the overall engineering plan, periodic pressure surveys are made. Complaints of poor water service are also checked against planned operation. The operation policy is to render an adequate and dependable water supply to all consumers at all times. During the war years, this has at times been difficult, but, with a little more time and the delivery of some needed materials, the policy will again be maintained.

All the factors involved in such operation make necessary continuous checks on equipment. In doing this, three principal checks are made regularly on all operating equipment.

The first check is made in the statistical branch of the engineering department. All field pumping records are assembled and checked in the office and the performance of each pumping plant is checked each month. A computation is made of the power in kilowatt hours consumed in pumping 100 cu.ft. of water (the company's unit of water measurement). This figure is balanced against the pumping water level in the well to determine the power, in kilowatt hours, required to raise 100 cu.ft. of water 100 ft.

The second check is the reading of power and water meters by the field operator on his daily rounds.

The third check immediately follows any variation in the consumption of power per 100 cu.ft. of water produced. This is the field check by engineers of the construction department of the efficiency of all the pumping units at the plant.

Wear or corrosion is immediately evident from one or all of these checks. During the war, when materials were difficult to obtain, these checks became very important; they were the insurance against failure of the primary supply of water. The importance of this insurance lies in the fact that the

total number of customers served during the last five years has increased nearly 10 per cent, whereas the available capacity of turbine pump production has decreased slightly. The result is that on maximum days every piece of equipment is in operation to meet the maximum hour.

Maintenance Program

Both the construction department and the engineering department work in close co-ordination on all phases of the company's operations. Seventeen years of co-operation has built up mutual understanding of the problems of each department. The result has been the adoption of certain theories and policies regarding design, maintenance and repair and operation.

The turbine pump maintenance program attempts to keep equipment in the best operating condition possible. Experience has shown that this policy can be carried out by pulling pumps for overhaul every 2, 3, 4 or 5 years.

Two-year schedule. Where the pumps are operating in "bad water," containing iron and sulfur organisms, or iron and manganese accompanied by hydrogen sulfide, or in wells which produce large quantities of sand, with the pumps operating under heavy-duty conditions—that is, for long hours every day in the year—a 2-year overhaul interval is scheduled.

Three-year schedule. No pump in "bad water" is permitted to operate beyond a 3-year period, regardless of the number of hours which it may have operated. Normally, heavy-duty units are overhauled on a 3-year period, even in good quality waters.

Four-year schedule. Pumps operating under relatively light duty and under "fair" water quality conditions are overhauled every 4 years.

Five-year schedule. Regardless of the characteristics of the water or the conditions of pump operation, no pump is permitted to run more than 5 years without an overhaul.

Extent of Repair and Replacement

When pumps are pulled from the well they are completely disassembled in the field or in the pump company's shop. Each part is subject to inspection by a trained engineer.

Generally, the inspections reveal the need for the following repairs:

Bowls

The top and bottom bearings or bushings are replaced. The replacement of main bearing housings or castings, however, is seldom needed. New wear and seal rings are nearly always installed, on both intermediate bowl castings and impellers. Intermediate bowl castings are replaced when not sufficient metal remains to permit machining for the installation of new rings or when excessive corrosion or sand cutting is apparent; and impellers are replaced for the same reasons. A new stainless steel pump shaft is installed only if injured in disassambly or when there is a change in basic bowl design.

Column

The most serious pump column replacement problem occurs with that portion of the column immediately above the pump bowls. This section is subject to more corrosion, sand cutting and wear of all sorts than any other, probably as a result of some turbulence in the water as it leaves the bowls. The first joint of casing above the bowls generally needs replacing or "pup jointing," that is the replacement of a portion of the casing

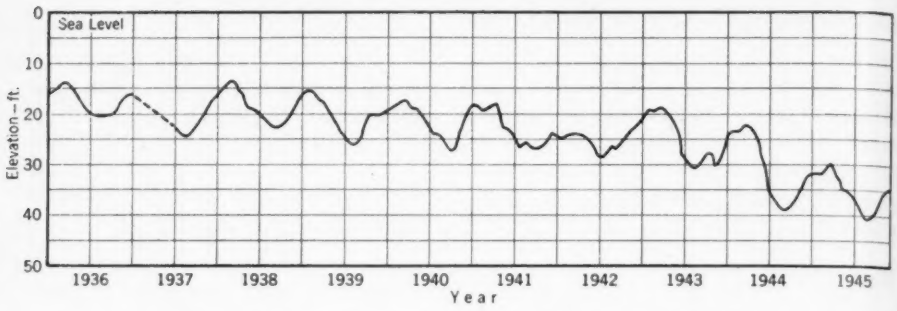

FIG. 3. Variations in Static Water Level of a Well

with new pipe. Pup jointing is accomplished by cutting off the corroded section and using a pipe coupling to install a short piece of pipe that makes up the required length. The oil tubing often shows results of corrosion both inside and outside, between the static and pumping water levels. This occurs because water alternately will rise within the oil tube to the static water level of the well and drain out to the pumping water level during operation. The line shaft also becomes corroded within this range and must be turned end for end and reground at the bearing points on each overhaul. Often individual pieces of shaft can be shifted within the assembly to overcome wear or corrosion. The line shaft bearings or tubing couplings are all sized, and are replaced if they show wear of 0.012 in.

Motors

For each overhaul, motors are taken to the company's electric shop, where they are cleaned, reinsulated, and have their bearings checked, so that the motor goes back as nearly as possible in perfect condition.

Manufacturers' Service

Even under emergency conditions, working around the clock, it requires two or three days to pull, tear down, inspect, repair and reinstall a deep-well turbine pump. Failures of pumping equipment occurring on peak days or even peak months can be serious. It is the general practice in designing water supplies utilizing ground-water reservoirs to have primary capacity to meet at least the maximum day. Maximum hours can be taken care of by elevated storage.

During the war, it was nearly impossible to obtain sufficient materials to keep production facilities ahead of demand. It seems even more difficult now. The rate of population growth in Southern California is greater than ever before. It is, therefore, highly important to keep equipment in the best possible condition.

Emergencies, however, do occur. It is then necessary to move, and to move quickly. The company has always required that repairs be made by the manufacturer. Consequently, deep-well pumping equipment is purchased only from those manufacturers who are prepared to render immediate service. Only three manufacturers who can meet this specification have yet been found.

Choice of Pump

As is true in any arid country, Southern California has cycles of rainfall.

These cycles recur from season to season and from year to year. The result is that the underground storage, as reflected in static water levels, varies both seasonally and by cycles of years. The season-to-season cycle indicates a range—often as much as 50 ft.—from a high in February and March to a low in September and October. These general conditions are illustrated in Fig. 3, which shows the variation in static water levels for a 10-year period on one company well.

Various water-bearing formations, whether Recent, Pleistocene or Pliocene, show different productivities. This productivity can be rated as the production volume in gallons per minute per foot of drawdown, and is the slope of Curve A, Fig. 4. The most economical production is always on the straight line portion of the curve, a short distance before the accelerated downward slope begins. No pump is ever chosen with a capacity greater than the most economical production of the well, as this factor seldom coincides with the maximum efficiency of the pump. Figure 4 shows the design conditions of a recent well. The well was completed in the high static water level period and drawdown Curve A was obtained from test. Curves B, the average static water level, and C, the low static water level, have been estimated from experience. Curves D and E are those submitted by two manufacturers for head capacity performance of a turbine. Curves D–1 and E–1 are the efficiency curves (ratio of power input at the meter to theoretical power required) and include all losses incurred in the motor, line shaft and bowls, and within the pump by water friction. Both performance curves were submitted by pump manufacturers to meet the design point.

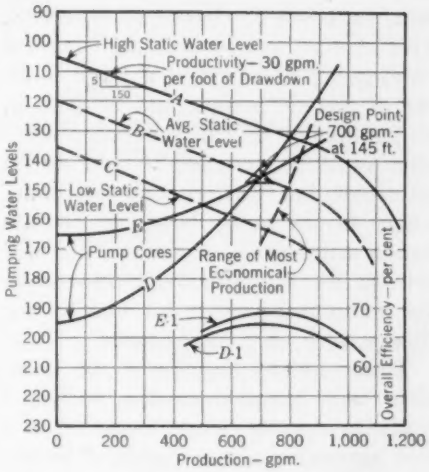

FIG. 4. Design Conditions for a Well

It is interesting to note that turbine pumps are sold and purchased to meet one design point. This practice, promoted by the California Pump Assn., has been followed for years. The association has set certain standards of manufacture and fabrication and, for the sake of uniformity, a pump with a given head capacity and a given column length will be sold by all manufacturers at nearly the same price. Price, therefore, is not the controlling factor.

Even though its efficiency was less at the design point, pump D was chosen for the well because: (1) Pump E, at high water level, would operate below the range of most economical production; (2) the head capacity curve of D more nearly follows the range of the most economical production; and (3) Pump D produces more water when it is needed in summer low-water period.

A new condition has recently been imposed and influences the final choice of the bowl assembly. The Southern California Edison Co., whch is now producing a 50-cycle alternating cur-

rent, proposes to change to 60-cycles. This change will require the complete redesigning of bowls in a large number of turbine pumps, and to meet it, all pumps that will be purchased hereafter must be designed to operate on 60 cycles, but with enough additional stages in the pump bowls to operate temporarily on 50 cycles. This will provide for a minimum of changes in the pump and prepare for making the change with all possible speed.

The company purchases the complete unit installed in the well and ready to operate when electrical and pipe connections are made. The responsibility for individual parts of the units rests entirely with the one manufacturer, who is required to guarantee not only the pump but the motor he furnishes with it. The efficiency test following the purchase is for over-all efficiency of the complete unit.

Specifications

The standard specifications provide for the majority of operating conditions, although special conditions, already mentioned, at times require revision of the standards. Generally, the specifications are as follows:

Bowls

All bowl castings, including top and bottom bearing housings, shall be of the best grade iron used by the manufacturer. The impellers shall be of bronze containing 85–88 per cent copper, 5–10 per cent tin and 2–5 per cent zinc, and may have 5 per cent lead if the same bronze is used for both impellers and line-shaft bearings. They shall be machined so that no rough surfaces are in contact with the water. The pump shaft shall be of stainless steel. The suction shall be 10 ft. of standard pipe with a standard "Greene" strainer.

Pump Column Assembly

The line shaft shall be of cold-rolled steel with surfaces polished and shall be in 10-ft. lengths joined with couplings to permit butting of the shaft within the coupling. The oil tubing shall be in 5-ft. lengths joined with bronze guide bearings to provide a bearing at 5 ft. intervals on the line shaft. The eduction pipe shall be of standard weight pipe, joined in 10-ft. lengths. Spider guides shall be installed within the column at the points indicated on the well survey diagram.

Design Point

A performance curve of the proposed pump shall be submitted, indicating the performance of the pump from shut-off to its point of cavitation and showing the over-all efficiency curve. This efficiency curve shall show the guaranteed field performance of the pump as installed, and shall be computed by relating the power of input to the unit to the theoretical water horsepower.

Pump Head

The pump head shall be the heaviest casting constructed by the manufacturer to receive the motor required for the pump, have a discharge nipple of the same diameter as the pump column, and be at least 2 ft. long.

Motor

The motor shall be of such size that at no point on the performance curve will the rated horsepower of the motor be exceeded. The motor shall be a 440-v., 50-cycle, 3-phase, vertical, hollow-shaft motor. It shall be designed to receive an adequate thrust bearing.

Manufacturers' Specifications

The manufacturer shall submit complete manufacturing specifications which

show the sizes of various parts of the column and the number of stages in the bowls. The speed of operation of the motor shall also be given, as well as the name of its maker.

The value of these specifications has been proved through extensive use. They standardize and simplify the problems of selection and maintenance of deep-well pumps.

DISCUSSION—*T. E. Larson*

Chemist, Illinois State Water Survey, Urbana, Ill.

Corrosion experiences with deep well turbine pumps may or may not be considered serious, depending on the local physical conditions and the maintenance care provided. The economics of proper maintenance sometimes permits a $400 replacement at a 100-ft. setting biennially, with no regard to excessive corrosion rates, or may necessitate a $6,000 expenditure to pull a pump at a 600-ft. setting and replace column pipe, shaft and shaft tube.

There is, however, little doubt that turbine pumps will corrode. A recent inspection of eleven turbine units abandoned by the Chicago, Milwaukee, St. Paul and Pacific Railroad Co. showed that seven of these had been abandoned because of corrosion, two because of sand erosion, one because of corrosion and obsolescence, and one, apparently, was as good as new. These pumps had been removed from wells widely distributed through the midwest and may be taken to indicate that the problem of pump corrosion is not local. The cost of these turbine units per million gallons of water pumped is shown in Table 1. These figures are very high compared to others which have shown the cost to be as low as 1¢ and less per mil.gal. during the lifetime of the pump.

During the past two years, about 50 Illinois pumps were inspected, and nearly all of these units showed evidence of corrosion from one or more causes. In general, four different types of attack, appearing alone or in combination, are recognized.

Galvanic Action

The ordinary galvanic attack is aggravated if two galvanic cells are set up in series in the installation. Such a situation exists if bronze impellers are used with cast-iron bowls and copper-alloy bearing-retainers are used with a water-lubricated steel shaft. In oil-lubricated pumps, the galvanic series is created if bronze impellers are used with cast-iron bowls and water is permitted to enter the enclosure tube above the bowls and to come in contact with the bronze bearings and steel shaft. It is obvious in these situations that current will flow from the iron impeller seats through the water to the bronze impellers and up the shaft to the bearings. At this point the current will leave the shaft and flow through the water to the bearing retainers or to the bearings and down the column pipe or enclosure tube to the bowls. A vicious cycle of galvanic action can be set up in this manner.

Water-Line Corrosion

Water-line corrosion is usually due to the existence of an "oxygen concentration cell" near the water line on the outside of the column pipe, and is adequately described in many texts.

TABLE 1

Pump	Length of Service *years*	Water Pumped *mil. gal.*	Cost *$ per mil. gal.*	Total Dissolved Solids *ppm.*	Clearance at Wear Ring *in.*
A	4	550	.40	530	$\frac{3}{64}$
B	2	440	.40	468	$\frac{4}{64}$
C	7	230	.49	1980	Semi-open impellers
D	$6\frac{3}{4}$			390	$\frac{1}{64}$
E	6	157	.77	310	$\frac{1}{64}$
F	13			570	
G	$1\frac{1}{2}$	30	8.10	990	$\frac{5}{64}$ (sand)
H	$1\frac{1}{2}$	33	7.80	990	$\frac{5}{64}$ (sand)
I	2	44	12.00	1980	Semi-open impellers
J	$2\frac{1}{2}$	54	9.80	1980	Semi-open impellers
K	$1\frac{1}{2}$	263	1.50	660	0

Carbon Dioxide Corrosion

Carbon dioxide corrosion takes place at the high-pressure points in the pump bowls and between the column pipe and shaft tube. It causes noticeable pitting in the bowls, on the column pipe and shaft tube just above the bowls, and, to a lesser extent, just above the spiders.

A possible explanation of this type of corrosion is that it is caused by the release of gas bubbles in the water at the low-pressure points on the underside of the impellers and possibly at the entrance to the suction pipe. This can happen, particularly if rough edges are present. The gas is composed of nitrogen, water vapor and carbon dioxide, and can be expected in any ground water under artesian pressure. When formed, the gas bubbles pass through the turbine and column pipe and undergo changes in volume due to the changes in pressure that take place. They are carried through the pump into the column pipe.

A rapid increase in pressure gives the carbon dioxide a higher solution potential and, as it dissolves, the water film on the surface of each bubble becomes excessively acid through the formation of carbonic acid. As the gas bubble with its acidic surface film passes over metal, corrosive action takes place. This type of corrosion has been recognized at the high-pressure points on the vanes in the bowls, at points inside the column pipe located from 6 in. to 2 ft. above the top of the bowls and at points located several inches above the spiders between the pump shaft or shaft tube and the column pipe. The extent to which this corrosion is noted above the spiders decreases with increased distance above the pump bowls. This decrease is due to the fact that, as the water moves up the column pipe, the size and carbon dioxide pressure within the bubbles decreases and the relative amount of corrosion decreases accordingly. The presence of hydrogen sulfide may accelerate this form of corrosion, and a "worm-eaten" shaft or shaft tube is common evidence of extreme cases.

Stray Currents

Stray currents are known to exist at many installations. To what extent they may damage the pump will depend on whether the polarity at any point enhances or inhibits corrosion. It has been noted that in all but one case out of 21, the well casing was of negative potential with respect to the column pipe or to the discharge line. In about half of 36 tests, mostly in the Cook County, Ill., area, the potential varied in magnitude. An alternating-current potential is seldom recorded, but in one well such a potential was observed between the power cable conduit and the pump head. Excessive corrosion was noted at this installation. A duplicate installation 30 ft. away had little corrosion as the cable emerged from the conduit and no metallic contact to the pump head was present. Both pumps discharged by free fall to an open reservoir.

The literature indicates that stray alternating shaft currents have been noted to cause corrosion at bearings in industrial motors and generators, and that alternating currents have also been proved to be corrosive to underground lead cable sheaths.

Prevention of Corrosion

Prevention of corrosion depends largely on the type of installation, the corrosion expected or encountered and the economics involved. Consideration of the savings effected by preventive methods should include the power saved by maintained pump efficiency and the trouble and cost of pulling the pump, as well as the cost of actual replacements.

It has obviously been recognized that certain parts of the pump are more important to efficiency than others, and the selection of materials has often been such as to protect the vital parts at the expense of the rest of the pump. The effective use of bronze impellers and, recently, stainless steel impeller shafts and even bronze or rubber wear rings is self-evident. The additional cost for bronze bowls amounts to about 80 per cent of the cost of the turbine unit, but is often only about 5 to 20 per cent of the cost of the total installation.

These improvements are not always enough. Perhaps more attention should be given to reducing the length of the tail pipe to 5 or 10 ft. and to maintaining the pumping level above the bowls in order to reduce the formation of carbon dioxide gas bubbles.

For deep settings, a protected column pipe and shaft tube is almost a necessity. Protection can be had at an added cost of 5 to 50 per cent of the cost of the pipe itself. It is essential that any coating be applied only on a clean and dry metal surface. An inexpensive coating properly applied is more satisfactory than an expensive coating that has been poorly applied on a dirty surface.

Cathodic protection installations have been made in Illinois but have not been in use sufficiently long for their economic value to be judged, nor has there been an opportunity to inspect a pump protected by this means.

Stray current electrolysis has been combated by inserting insulation between the discharge line and the pump head. Sometimes the well casing is also insulated from the pump head and column pipe. Where such measures are taken, it is imperative that the housing for the power cables and the return water lines for water-lubricated pumps should also be insulated from the pump head, or the efforts will be nullified.

Abstracts of Water Works Literature

Key: In the reference to the publication in which the abstracted article appears, **34:** 412 (Mar. '42) indicates volume 34, page 412, issue dated March 1942. If the publication is paged by the issue, **34:** 3: 56 (Mar. '42) indicates volume 34, number 3, page 56, issue dated March 1942. Initials following an abstract indicate reproduction, by permission, from periodicals, as follows: *B.H.—Bulletin of Hygiene (British); C.A.—Chemical Abstracts; P.H.E.A.—Public Health Engineering Abstracts; W.P.R.—Water Pollution Research (British); I.M.—Institute of Metals (British).*

CORROSION AND CORROSION CONTROL

Anaerobic Corrosion of Iron in Soil. ROBERT L. STARKEY & KENT M. WIGHT. American Gas Assn., 108 pp. (1945). Steel and cast iron corrode in soil under anaerobic conditions even where there is no stray current electrolysis or corrosion caused by high acidity or galvanic couples. Corrosion products not adherent type which tend to stifle corrosion, but porous or soft, and leave metal without protective surface film. When corrosion products wiped away, metal surface found bright and silvery and has etched appearance. Such metal surface corrodes readily and rusts rapidly in contact with air. Products of anaerobic corrosion also rapidly oxidized. Evidence obtained indicates that, in anaerobic corrosion, sulfate-reducing bacteria may be of major importance. Characteristics of these bacteria and importance of process of sulfate reduction caused by them discussed. According to theory of von Wolzogen Kühr, sulfate-reducing bacteria consume hydrogen which is formed at cathodes on metallic iron and, by thus depolarizing system, make possible continuation of corrosion process. Addnl. evidence in support of microbiol. theory of anaerobic corrosion obtained from studies of ability of sulfate-reducing bacteria to oxidize gaseous hydrogen. Pure cultures of *S. desulfuricans*, cultivated for over 2 yr. on org. media, oxidized hydrogen when cultivated in medium contg. sodium lactate. Crude cultures and partly purified cultures of sulfate-reducing bacteria oxidized hydrogen in strictly inorg. medium. Evidence indicates that sulfate-reducing bacteria able to grow by energy provided by reaction whereby hydrogen oxidized and sulfate reduced to sulfide, but absolute purity of cultures not established. Purified cultures of sulfate-reducing bacteria developed in strictly mineral medium to which no hydrogen added, but which contained steel from which hydrogen produced through reaction with water. Possibility indicated that not only sulfate-reducing bacteria but other bacteria as well promote corrosion by removal of cathodic hydrogen. On basis of soil tests—in particular, measurements of soil Eh and pH—possible to predict severity of anaerobic corrosion of steel and cast iron in soil. Method devised whereby measurements could be made readily and rapidly in field without soil sampling. Use of tests for predicting corrosiveness based on principle that bacteria responsible for anaerobic corrosion thrive and cause destruction of iron and steel only near neutrality and under strongly reducing conditions. Results obtained support this concept. Certain limitations to use of soil measurements for predicting severity of anaerobic corrosion became evident during course of investigation; these follow: Reaction range for development of *S. desulfuricans* in culture medium found to be pH 5.5–8.5. Also been found that, in soils, anaerobic corrosion most severe at reactions close to neutrality and acid limit for development of sulfate-reducing bacteria in culture media close to limit for corrosion in soil. Soil reaction when considered together with other soil characteristics, particularly soil redox potential, served as useful index of soil corrosiveness. Soils more acid than pH 5.5 considered unfavorable for anaerobic corrosion, and no evidence of anaerobic corrosion noted in soils more acid than pH 5.5 where no soil abnormalities and interfering factors such as

stray currents. Redox potential of culture media used for cultivation of *S. desulfuricans* initally 300 to 400 mv. and dropped to −200 to −300 mv. during growth of bacteria. Nearly as low potentials produced in sterile medium to which sulfide added. Eh of sterile media to which metallic iron added became stabilized at approximately −400 mv. and this potential remained unchanged even after growth of *S. desulfuricans* in medium. Lab. tests indicated redox potentials of aerobic soils sufficiently greater than those of anaerobic soils to make possible use of potential measurements for differentiation of aerobic from anaerobic soils in field. Eh of rapidly decomposing plant residues low even when materials kept moist and presumed to be decomposing aerobically, but slowly decomposing plant residues had higher potentials. Similar plant residues decomposing under anaerobic conditions had low potentials. During decomposition of org. materials in moist soil, however, redox potentials remained high (above 400 mv.), and rapidly decomposing org. matter had no apparent effect on potentials of soil as whole. When similarly treated soils waterlogged, potentials dropped to below 200 mv. Potentials of fertile topsoil to which no org. material added underwent same changes as soil receiving addns. of org. matter. Subsoil, deficient in org. matter, showed scarcely any decrease in redox potential upon being waterlogged except when org. matter added. Possibility of using potential measurements other than direct measurements of soil Eh for detg. deg. of soil anaerobiosis considered. Differences in potentials of acid extracts of aerobic and anaerobic soils comparatively small and potentials showed little correlation with deg. of soil reductiveness. Anaerobic soils could in most cases be distinguished from aerobic soils by potentiometric titrations of acid extracts, but large quant. differences among strongly reduced soils; these differences appeared related to chem. compn. of soils, particularly iron content. Method had limited value with sandy soils and peats. Potential measurements of alk. extracts of soils proved of no value for differentiating aerobic from anaerobic soils. Value of potential measurements other than direct measurement of soil redox potential further limited for field studies by fact that measurements time-consuming and necessitated taking soil samples. Desirability of measuring soil Eh and pH directly and *in situ* discussed. Indicated that there may be errors when measurements made on soil samples, particularly those of strongly reduced soils. Through contact with air, Eh of samples of reduced soils increased. When reduced soils contg. sulfide desiccated, pH became more acid; in some cases drop of 2.0 pH units or more. Instrument devised whereby measurements could be made of soil pH and Eh in field to depths of 3–4′ without soil sampling. Instrument particularly well adapted for use in wet, but not in dry or moist soils. Limitations of common methods of cleaning platinum electrodes for use in Eh measurements indicated. Improved method devised which was well adapted for use in field. Procedure involved cleaning with acid soln. of synthetic detergent and soln. of hydrogen peroxide. Results reported of tests made on numerous soils in N.Y., N.J., Pa., Ohio and Md., along pipeline distr. systems of 6 gas utility companies. Characteristics of soils noted and tests made to det. severity of corrosion of pipes buried in soils and factors responsible for corrosion. Soil pH and Eh measured and deg. of correlation between magnitude of soil Eh and severity of corrosion ascertained. Scale formulated for estg. soil corrosiveness from soil redox potential:

Range of soil Eh	*Corrosiveness*
Below 100 mv.	Severe
100 mv. to 200 mv.	Moderate
200 mv. to 400 mv.	Slight
Above 400 mv.	Non-corrosive

Severity of anaerobic corrosion of each site classified on basis of both soil Eh and condition of pipe. Deg. of agreement between 2 classifications served to indicate merit of soil test as index of corrosiveness. In estg. corrosiveness from soil measurements, soils with reactions more acid than pH 5.5 considered to be unfavorable for anaerobic corrosion. Results obtained at 48 test sites where there was min. of complicating corrosive factors showed that corrosiveness correctly estd. by soil tests in 67% of cases and estd. with fair deg. of accuracy in 23%; prediction poor in only 10% of cases. High deg. of correlation between soil Eh and corrosiveness indicates that this soil measurement can be used as basis for estg. severity of anaerobic corrosion. Noncorrosive and severely corrosive soils showed best correlations, and borderline soils with intermediate redox potentials between 100 and 400 mv. showed greatest discrepancies

between predicted and actual corrosiveness. Correlation between 2 classifications of corrosion less satisfactory with series of test sites where there were abnormal soil conditions or complicating corrosive factors such as seasonal variation in deg. of soil reductiveness or stray current electrolysis. With 14 abnormal test sites, severity of anaerobic corrosion accurately estd. in 36% of cases, judged with fair accuracy in 50% and poorly evaluated in 14%. Results suggest that even where there are soil abnormalities, severity of anaerobic corrosion can be estd. with fair deg. of accuracy from measurements of soil Eh and pH, but probability great that prediction will be inaccurate. Anaerobic corrosion most severe in wet, poorly drained soils which had low redox potentials between 0–100 mv. Soils had reactions close to neutrality and generally contained iron sulfide. Soils with moderate corrosion had somewhat higher redox potentials, between 100–200 mv. Anaerobic corrosion not encountered in aerobic soils which had redox potentials greater than 400 mv. except where conditions complicated by such factors as seasonal variation in soil conditions and stray current electrolysis. No correlation noted between soil texture and severity of anaerobic corrosion. Soil drainage better index of corrosiveness than soil texture. Anaerobic soils of coarse texture always near rivers, lakes, swamps, or ocean, which kept them satd. with water at pipe depth. Heavy soils poorly drained and anaerobic not confined to locations near bodies of surface water. Development of anaerobic conditions in poorly drained soils by stagnation of water provides conditions favorable for anaerobic corrosion. In cases where soil water in motion, however, soil redox potential generally high and no anaerobic corrosion. Potentials of acid extracts of soils showed no consistent correlation with severity of anaerobic corrosion. Reducing capacs. of anaerobic soils much greater than aerobic soils, but no close quant. relationship found between deg. of soil reductiveness and value of reducing capac. Reducing capacs. of sands and peats relatively low, irrespective of deg. of reductiveness of soil or severity of corrosion. At sites where soil conditions and corrosion affected by stray currents, seasonal variation in deg. of soil aeration, and presence of consumer gas originating from leaking gas pipes, soil tests had limited value as basis for estg. severity of anaerobic corrosion. No consistent correlation between soil Eh and severity of anaerobic corrosion in these cases. At sites where metal became cathodic periodically under influence of stray currents, evidence of anaerobic corrosion even in aerobic soils. Seasonal changes in level of soil water table resulted in variation in deg. of soil aeration in certain soils. During most of year soils contained free water, were poorly aerated and anaerobic, had low redox potentials, and nearly neutral in reaction. During dry seasons soils at pipe depth had high redox potentials and became dry, well aerated, and fairly acid in reaction. Correlations between soil Eh and severity of corrosion could be obtained in such cases by making tests at periods when soil conditions representative for location. In some soils redox potentials varied markedly during year. Presence of consumer gas in soil interferes with measurement of soil redox potential. Consumer gas caused potentials of aerobic soils to drop rapidly to values typical of anaerobic soils. Similar but less persistent changes in Eh produced by hydrogen gas.—*Ed.*

Anaerobic Corrosion of Buried Iron Pipes. O. B. WILSON. Wtr. & Wtr. Eng. (Br.) **48**: 594 (Nov. '45). This type of corrosion of steel and c-i. pipes common in conditions such as prevail in wet heavy clay soils, and is result of activity of sulfate-reducing bacteria of type *vibrio desulfuricans*. Organisms cause sulfate present in soil to act as hydrogen-acceptor and so cathode is depolarized. Iron sulfide formed by interaction of iron dissolved at anode with hydrogen sulfide produced bacterially. Effect is such that material becomes soft, and, while retaining outward appearance, can easily be cut with knife. Of several cases examd. only one of clays gave other than neutral or alk. reaction. In other cases pH varied from 7.0 to 7.8. Sulfate-reducing bacteria should not be confused with common iron bacteria which are aerobic; sulfate-reducing organisms strictly anaerobic. Products of bact. corrosion are: ferrous hydroxide, white pasty mass which on oxidation slowly turns brown; and black ferrous sulfide, also easily oxidized. Following eq. illustrates that bacteria can utilize hydrogen in org. food to produce hydrogen sulfide, sodium lactate being taken as org. food:

$$2C_3H_5O_3Na + 3CaSO_4 = Na_2CO_3 + 3CaCO_3 + 2CO_2 + 2H_2O + 3H_2S$$

Hydrogen sulfide available for pptn. of ferrous ions as ferrous sulfide and, consequently, ferrous hydroxide not found in any great quant. Cellulose-decomposing bacteria widely distributed in almost all types of soil, and hessian or other cellulose material provides source of org. food for these organisms. Difficulty experienced in obtaining specimens of products of corrosion because: (a) where leak has occurred, corrosion products leached out and chemically changed and rust everywhere apparent; (b) portion examd. restricted and (c) ferrous sulfide in corrosion products easily oxidized. Important that samples be taken under water and containers filled and sealed. Sample of soil taken from near water main which had failed in 4 yr. was of clayey nature and contained limestone and org. matter. Active soil placed in beaker and covered with neutral water to depth of 2" standing in middle was clean steel nail. Soil became darkened and as time went on black deposit formed. Sulfide-sulfur in deposit was 33.83%. Piece of pipe which had failed painted and subjected to attack of active bacteria, fed on sodium lactate, calcium sulfate and water, and showed no effects after 2 yr. of exposure. It follows that no anaerobic corrosion will take place if pipes left in ground with coating undisturbed. Concluded that attention required when laying mains in order that org. matter in contact with pipes be reduced to min. In locating this type of corrosion 2 deciding factors: (1) Necessary that earth be water-satd. or airtight, and (2) pH of soil water must be approx. 7.0, limiting deviation of which is 0.8.—*H. E. Babbitt.*

Corrosion Tests Yield Interesting Data. ANON. Ry. Age **119**: 15: 594 (Oct. 13, '45). Full description of test facilities at Kure Beach, N.C., where thousands of specimens of metals, alloys and coatings studied in natural atmospheric corrosion environment and also effect of methods of timber preservation to det. resistance to marine borers. Investigation is co-operative study by several large companies with approximately 15,000 specimens exposed to sea air and 3000 specimens comprise submerged tests in sea water. —*R. C. Bardwell.*

Corrosion Tests for Water Works Materials. L. W. HAASE. Korrosion u. Metal. (Ger.) **19**: 224 ('43). Methods in which flowing liquid used recommended for detg. corrosion-resisting properties of materials used in water works; number of lab. devices used for purpose described and illustrated. When compn. of corroding liquid materially changed, liquid withdrawn and analyzed. Fresh liquid then used for same period of time as before; this liquid then withdrawn and analyzed. From anals. it should be possible to obtain some indication of whether protective coating being formed on surface of material. Throughout tests concn. of oxygen in liquid should be kept const. Salt spray tests can be used to det. porosity of protective coatings. Conditions under which tests are carried out should be as nearly identical as possible to those maintd. in practice.—*W.P.R.*

Long-Term Tests With Concrete Pipes. H. GRANHOLM. Chalmers Tekn. Högsk. Handl. 27 ('44). Concrete pipes of different types exposed to moorland water for 10 yr. Water soft, contained large amts. of aggressive CO_2 and had pH value which was sometimes as low as 4.5. Pipes of porous material almost completely destroyed by end of period; pipes of dense, impermeable material, however, only slightly corroded. Surface coatings of asphalt solns. and molten asphalt protected pipes of porous concrete from attack by water.—*W.P.R.*

Corrosion of Cement and Concrete. C. HAMMERTON. Surveyor (Br.) **104**: 123: 127 ('45). *Discussion.* C. B. TOWNEND said corrosion of concrete due to hydrogen sulfide not very prevalent in Britain except where temp. and other conditions abnormal; septicity of sewage due to deposits formed in sewers laid to too low gradients. No reason why sewers should not be laid to gradients which would obviate the formation of deposits. Adequate ventilation of sewers best method of preventing sewage from becoming septic. Aluminous cement might be attacked by strong alkali in trade waste waters. B. A. SOUTHGATE described expts. on action of waste waters from milk industry on cement mortars. L. A. ALLEN described work carried out at Water Poln. Research Lab. of Dept. of Scientific and Indus. Research on formation of hydrogen sulfide in sewage incubated at 20°C. Results showed that TNT, dinitrobenzene, sodium picrate and potassium nitrate delayed and, in sufficiently high doses, prevented formation of hydrogen sulfide in sewage. A. V. HUSSEY discussed resistance to corrosion of pozzolanic and aluminous

cements. J. B. HARVEY described disintegration of culvert through attack by hydrogen sulfide. "Ciment Fondu" used for repairing culvert and measures taken to ventilate culvert adequately. Although hydrogen sulfide still formed there has been no further corrosion. C. B. O. JONES said that in Coventry cement or lime mortar or both in 26 manholes corroded by sulfuric acid formed from waste water from rayon factory. Although waste water had pH value of 7.6–7.9, reduction products from compds. such as sulfates and thiosulfates condensed with droplets of moisture on unwetted side of manholes and reoxidized to sulfuric acid. *Author's reply.* Ventilation of sewer advantageous if it prevented formation of septic conditions or carried hydrogen sulfide away so quickly that oxidation products did not come into contact with sewer; if, however, septic action had already started vigorously, ventilation might accelerate oxidation of hydrogen sulfide and thus accelerate corrosion.—*W.P.R.*

The Corrosion of Concrete. C. D. PARKER. Australian J. Exp. Biol. Med. Sci. **23**: 81 ('45). (1) Isolation of species of bacterium associated with corrosion of concrete exposed to atms. contg. hydrogen sulfide. Internal surfaces of concrete sewers often subject to rapid corrosion when sewage and atm. in sewers contain appreciable amounts of hydrogen sulfide. Constituents of cement converted to sulfates and high concn. of sulfuric acid often found in water associated with products of corrosion. Five strains of species of bacterium isolated from corroded concrete. Method of isolation and morphology and cultural and biochem. characteristics of organism described. Organism named provisionally *Thiobacillus concretivorus*. All 5 strains grew only under acid conditions and able to utilize free sulfur and thiosulfate as sources of sulfur; no growth occurred when source of sulfur was sulfite, sodium sulfide or hydrogen sulfide. When free sulfur utilized all 5 strains produced sulfuric acid only; when thiosulfate source of sulfur, relative amts. of free sulfur and of sulfuric acid produced differed with different strains. (2) Function of *Thiobacillus concretivorus* (*nov. spec.*) in corrosion of concrete exposed to atms. contg. hydrogen sulfide. *Thiobacillus concretivorus* isolated from samples of corroded concrete from widely separated places in Australia. Corroded concrete found to be acid and to contain sufficient available phosphate, nitrogen and free sulfur for growth of organism. Expt. made in which culture medium used for isolation of organism placed in 2 flasks. Sterile block of cement introduced into each flask; part of each block submerged in medium. Sterile sulfur added to both flasks and one flask inoculated with *Thiobacillus concretivorus*. Because of soln. of lime from cement, necessary to adjust pH value of contents of flasks to 5.0 for some days before growth began. After incubation for 3–4 mos., considerable corrosion of cement had occurred in inoculated flask, but no corrosion had occurred in sterile flask. In another series of expts., blocks of cement-sand mortar exposed to atm. satd. with water vapor and contg. 0.5–1.0 ppm. ammonia and about 250 ppm. hydrogen sulfide. After exposure for 6 wk. mortar in flask inoculated with *Thiobacillus concretivorus* showed obvious signs of corrosion. Mortar in sterile flasks showed no signs of corrosion. After exposure for 15 wk. blocks in inoculated flasks showed all signs of corrosion normally found in sewers. Products of corrosion acid and contained sulfate. When blocks treated with hydrochloric acid, grey surfaces became coated with yellow solid, presumably sulfur. This more noticeable on blocks from sterile flasks and suggests that polysulfides formed under sterile conditions. Appeared to be slight conversion of hydrogen sulfide to sulfate under sterile conditions. Concluded that, normally, corrosion of concrete occurs in 2 stages. In first stage carbonate-bicarbonate-carbon dioxide equil. destroyed and pH value decreases from 8.4 to between 6 and 7. In second stage growth of *Thiobacillus concretivorus* occurs with formation of acid. Because of high pH value, unlikely that *Thiobacillus concretivorus* plays any part in first stage. Water extracts of sterile blocks used in expts. had pH values of 6.6–6.9; seems unlikely therefore that chem. changes alone would produce sufficiently low pH value for growth of *Thiobacillus concretivorus* and seems probable that other species of sulfur bacteria responsible for first stage of corrosion.—*W.P.R.*

Corrosion of Condenser Tubes by Ammonia. E. B. HARRISON. Power Plant Eng. (Br.) **48**: 6: 84 ('44). Corrosion of arsenical copper condenser tubes occurred at plant where 4 condensers in use. Although feed water had contained up to 0.5 ppm. ammonia for many years, only 1 condenser, which

differed in design from other 3, affected. Corrosion took place mainly in winter when low temp. of water caused almost complete condensation in first passage and led to formation of moderately concd. soln. of ammonia or ammonium carbonate in second passage. Considered that corrosion fatigue had increased damage. To minimize corrosion, temp. of feed water raised above 45°F. and 2 auxiliary air offtake connections added. Results of comparative tests using stainless steel, Admiralty metal, and arsenical copper tubes showed that arsenical copper tubes became corroded first and that extent of corrosion 8 times greater in arsenical copper tubes and 5 times greater in Admiralty metal tubes than in stainless steel tubes. Proposed to replace all faulty arsenical cooper tubes by special Admiralty metal tubes.—*W.P.R.*

The Principles of Electrolytic Corrosion of Metals. G. E. COATES. Chemistry & Industry (Br.) 306 ('44). Oxidation of metal, when it involves economic loss, termed corrosion. Tendency of metal to corrode may be expressed in terms of quant. of energy set free when atomic equiv. converted from metallic to oxidized state. Mechanism of corrosion in aqueous solns. discussed. Metals consist of pos. ions held together by electrons; when metal corrodes in aq. soln., pos. ions go into soln. Metal then becomes neg. charged and corrosion will not proceed unless neg. charge removed. In practice neg. charge removed by dischg. of pos. ions, commonly hydrogen ions, in soln. or by combination of electrons of metal with oxygen or other oxidizing agent to form hydroxyl or other negative ions. Either of these processes may occur not only at site of corrosion but also at electrode connected to corroding electrode and immersed in same soln. Secondary though very important factor influencing rate of corrosion, is deposition on corroding surface of insol. reaction products which retard corrosion.—*W.P.R.*

Cold Water De-aeration. N. HOLLEFRIEND. Modern Power & Eng. **39**: 12: 60 ('45). Cold water de-aerators require same conditions for successful operation as more familiar boiler feed water de-aerator: (1) Maint. of pressure within unit corresponding to b.p. of water under treatment; (2) means for dividing water into small and minute particles to expose surface and facilitate escape of gases from soln., (3) means for withdrawing gases from container, and maint. of const. vacuum. Sprays and cascades over trays within de-aerators generally used. Multiple-stage equip. may be required for removal of gases to low content. De-aeration will reduce corrosion of piping and other equip.—*C.A.*

Application of Equilibrium pH to Recirculating Cooling Water Systems. A. G. D. EMERSON. J. Soc. Chem. Ind. (Br.) **64**: 335 ('45). Theory underlying conditions required to be maintd. in recirculating cooling water systems to establish stable conditions and prevent corrosive attack studied. Accurate equations established enabling equil. pH value (pH_s) of water and optimum no. of concns. required in any given recirculating cooling water system to be calcd. Anal. detns. of Ca hardness, total alky., total dissolved solids and pH of water permit calcn. of pH_s, and finally "corrosiveness" calcd. as (pH_s–pH). Alteration in pH value by addn. of inhibitor to water should be detd. experimentally and suitable correction applied to observed pH before calcg. (pH_s–pH).—*C.A.*

Principles and Practice of Corrosion Prevention in Waterworks Pipelines. NORMAN J. PUGH. Wtr. & Wtr. Eng. (Br.) **49**: 57 (Feb. '46). Mass of literature devoted to corrosion evidence of importance and also monument to inability to explain or control ravages. Author advocates provision and preservation of protective coatings as most practical and effective corrosion preventive. In considering corrosion of pipelines, important to pay attention to those mains which, if they failed, would affect supplies to considerable areas. Estd. in '37 that corrosion costing world £5,000,000,000,000. Pipes constructed in non-corrodible material used in past few years. Materials allowed to waste at home must be replaced and in so doing materials may be diverted from export trade. Iron and steel remain as basic components in pipes for water works. Coupled with asbestos cement, these will remain for some time materials in which larger size water pipes mainly available. Corrosion-resisting qualities of asbestos-cement pipes commend them for use under certain circumstances, but even if used corrosion problem remains since metal extensively used in such pipelines for specials, jointing and tapping. Accompanying attempt to summarize major causes of corrosion and indicate methods of prevention. Little evi-

dence to condemn practice of using water mains as means of discharging stray elec. currents to earth. Report to South Staffordshire Mond Gas Co. provided positive evidence that corrosion on mains widely distributed over area under review due to heavy cathode points with corrosion taking place at adjacent anode points where induced currents dischgd. to earth, Report reads "We have established definitely that anode currents are harmless provided coating on main is perfect . . . pinhole is sufficient to start mischief." Use of electrically inert materials in water works pipelines open to objection from elec. industry. If communicating pipes to bldgs. are tapped off mains so constructed that there can be no elec. dischg. from mains, then stray currents can be dischgd. only through service pipework. In smaller pipes internal protection depends on initial coating and care taken not to destroy it during laying and jointing. In larger pipelines, where internal protection can be made good after laying should be possible to leave work so that corrodible metals effectively insulated from contact with water which will pass through pipes. External protection more likely to be damaged in transit, handling and installing than internal linings. In practice extremely difficult to avoid damage to outside protection on metal pipes. Pump suctions and suspended pipes in wells present special problem. Such pipes often alternately wet and dry and located where corrosive elements favored. Periodic inspection of suspended pipes advocated as matter of principle. Value of investigating corrosive characteristics of waters previous to pipe laying doubtful. River waters notoriously changeable in quality. At best, soil samples provide only "hit and miss" evidence and should not be regarded as evidence of safety throughout length of pipeline. Unfortunate that British Standard Specifications makes any attempt to prescribe coatings difficult if not impossible. Quotations from A.W.W.A. Standard Specifications indicate advantages and desirability of such specifications. They establish orderly procedure, remove doubt about untried procedures, benefit mfr. and contractor in defining properties and qualities of materials, and are easy for engr. to use. Technical staff may advise purchaser that greater degree of protection should be considered but if advice rejected pipes must be supplied to purchaser's inadequate specification or order will be lost. Conclusions: (1) Metal will continue to be used for water pipe and specials during earlier postwar years. (2) Extensive program of major permanent works about to be undertaken by water works industry with little improvement in materials since '39. (3) Durability of greater signif. now than ever before. (4) Inhibition of corrosion should be one of foremost concerns of water works industry. (5) Difficult to assess danger of corrosion to any particular pipeline. (6) Protection provides answer to problem of corrosion. (7) Metal in pipe should be regarded as strengthening component between layers of corrosion-resistant material. (8) Protection to be effective must be continuous. (9) Effective protective coatings involve care and attention. (10) More general appreciation of value of protective coatings desired. (11) Accepted standards of protection should be defined and applied throughout water works industry. (12) Standards of protection for metal pipes should apply to materials, manufacture and care and attention given to coatings in transit, storage, handling and laying procedure. *Discussions.* C. A. RISBRIDGER. Did not agree that external corrosion more to be feared. In own work all pipes concrete lined and laid-in, haunched and covered with concrete. F. H. BULLOCK thought author had dismissed internal encrustation without sufficient consideration, and emphasized importance of withdrawing suspended pipes from time to time for exam. H. F. CRONIN referred to long life of c-i. mains, vulnerability of steel mains and relative durability of spun against c-i. pipes. Most important to guard against damage to protective coatings during storage. F. C. BULLOCK anticipated greater danger from "pin point" corrosion. F. W. GASKIN agreed major factor in external corrosion is presence of excessive moisture. Pipes often act as drains to conduct water to lowest points in trenches where corrosion so often experienced. C. V. BROWN mentioned chlorine at 1 ppm. as inhibitor of internal corrosion. L. H. BROWN stated complete elimn. of protection does not necessarily give rise to rapid corrosion. D. G. BEVAN thought too great reliance should not be placed on concrete as protecting agent as some sulfate-bearing waters produce rapid disintegration of ordinary cements. Concrete surrounding iron or steel pipe might provide good (elec.) ground. C. C. JUDSON favored asbestos cement as water works pipe material. B. L. MCMILAN referred to dangers of accelerated

corrosion if communicating pipes laid in copper. In conjunction with ferrous metals likely to cause corrosion. *Author's reply.* Relative importance of internal and external corrosion depends on circumstances in each case. Evidence that partial protection may cause pipes to fail that might have remained serviceable for longer period. Dr. Angus Smith's soln. in original form, probably sound protection but in these days mythical. Coating pipes by dipping can be delusion. Internal encrustation not stressed because adequate protection deals equally with internal and external protection. Dept. of Scientific and Industrial Research conducting investigation which might answer question whether chlorine increases or inhibits corrosion. Extra cost involved in assuring pipelines are continuous conductors to provide elec. grounds should not fall on water works. Asbestos-cement piping normally protected against sulfate corrosion by dipping. Elec. testing of protective coating will detect "pinholing." Table of cause and prevention follows.—*H. E. Babbitt.*

CORROSION OF METALS IN PIPELINES

Causes	*Prevention*
Inherent in Metals	
Lack of homogeneity in structure of metals	Care and improvement in mfg.
Presence of other metals in alloys	Improvements in existing alloys and introduction of new types
Presence of non-metallic foreign matter	Continuation and extension of research with object of removing or minimizing bogey of corrosion in metals used for water works
Chem. composition	
Micro structure	
Physical conditions, impaired or influenced by methods of production	Care in mfg. and fabrication; avoidance of distortion or straining; care in welding
Affecting Pipelines Internally	
Reaction between water & metal:	
(a) Chem. or electrolytic	Conditioning of water; raising of pH value; internal protective coating
(b) Bacteriological	Complete sterilization; internal protective coating.
Accumulation of foreign matter in pipes	Care in laying and during subsequent repairs; conditioning of water
Contact with dissimilar metals	Elim. as far as possible in design and practice
Internal stresses and strains, causing failure of coatings and fatigue in metal	Regulation of pressures, prevention of surges, air valves, anchoring or strutting of bends
Perforation or breakdown of protective coatings	Selection of appropriate protective coatings; inspection prior to and after laying; care in laying and jointing
Affecting Pipelines Externally	
Reaction between ground and ground water and metal, or between atmosphere and metal	Selection of materials appropriate to conditions, selected filling to trenches, external protective coating.
Contact with dissimilar metals	Elimn. in design and practice as far as possible
External stresses and strains	Proper supporting of pipes, care in bottoming up and backfilling, laying pipes on even bed, avoidance of intermittent rigid supports
Effect of leaks from high potential circuits and grounding of elec. circuits and apparatus to pipes	See text
Perforation or breakdown of protective coatings	Care in selection of protective coatings, inspection before and after laying, care in handling and slinging pipes, care in laying pipes on even beds, avoiding sharp stones and boulders, care in refilling trenches, particularly in first 12" over pipes

Emulsions of Oil in Water as Corrosion Inhibitors. Overseas Engr. **18**: 173 ('45). In paper submitted to Iron Steel Inst., P. Hamer, L. Powell and E. W. Colbeck described prelim. expts. on use of oil emulsions, produced by adding "soluble oils" to water, to prevent corrosion in cooling water systems in which water recirculated. Concluded from results of expts. that oil emulsions can inhibit corrosion of mild steel to natural waters of widely different types at temps. up to 90°C. when water still or flowing. Metal surfaces which have been exposed to emulsions retain passivity in untreated water for limited time. Corrosion can be prevented by heavy dose of oil followed by continuous application of much smaller dose. Non ferrous metals, alone or in contact with mil steel, protected by oil emulsions at roo temp. when water still or flowing. At 60 and 90°C., however, local attack occurs o both steel and cast iron in contact with non ferrous metals. With mild steel or non ferrous metals, breakdown of emulsion ma be accompanied by pitting. Corrosion re tarded or stopped when oil emulsion in con tact with metal surfaces on which corrosio products present. Protection greater, how ever, when surfaces clean. Protective effec appears to be due to formation of oil film o surface of metal.—*W.P.R.*

Erratum

In the abstract of "The Chlorination of Mains and the Defects of Yarn as a Jointing Material," Vol. 38, p. 890, July, 1946, JOURNAL, the statement that "it was practice to chlorinate only repaired mains 12" and over in diam.," was in error. The statement should have read: ". . . it was practice to chlorinate mains less than 12" in diam. with bleaching powder—an unsatisfactory method. Mains 12" and over in diam. were dosed with 10 ppm. of chlorine for a ½- to 1-hour contact period, and this method was considered generally satisfactory."